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Puget Sound Dredged Disposal Analysis

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Benthic Resources Assessment Technique Evaluation of Disposal Sites in Puget Sound and Adjacent Waters

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BENTHIC RESOURCES ASSESSMENT TECHNIQUE EVALUATION

OF DISPOSAL SITES IN PUGET SOUND AND ADJACENT WATERS

by

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PREFACE

INTRODUCTION

1. The U.S, Army Engineer District, Seattle is currently involved in a decision-making process regarding the designation of open water dredged material disposal sites in Puget Sound and adjacent waters. In 1985 the Puget Sound Dredged Disposal Analysis (PSDDA) study, a joint effort among the Corps of Engineers, Environmental Protection Agency, and the Washington Departments of Natural Resources and Ecology, was initiated to examine long-term requirements and strategies for open-water disposal of dredged materials. The quality of benthic habitats at proposed disposal sites was identified as a major topic of interest in the PSSDA study because of potential impacts to demersal fish feeding habitat. sites.

2. One aspect of benthic habitat quality is the relative amount of trophic support that a given benthic habitat provides demersal bottom-feeding fishes. Analytical procedures have been developed at the U.S. Army Engineer Waterways Experiment Station (WES) with funding from the Corps of Engineer's Environmental Impact Research Program to estimate this aspect of benthic habitat quality. These procedures are collectively called the Benthic Resources Assessment Technique, or BRAT (Lunz and Kendall, 1982; Clarke and Lunz, 1985). The BRAT analysis involves the collection of two data sets; one which describes benthic biomass in terms of size and vertical distribution in sediments at selected sites, and a second which describes the foraging depth and prey size exploitation pattern of demersal fishes at those sites. The BRAT then estimates that portion of the total benthic infaunal biomass that is both available and vulnerable to predation by target fishes.

3. During the period of 13 June to 8 July 1986, benthic box-corer and otter trawl samples were collected at four areas identified as zones of siting feasibility for unconfined open-water disposal sites in Puget Sound. This report presents the results of a BRAT analysis of these samples.

METHODS

4. Field sampling was performed at four locations: Commencement Bay, Elliott Bay, Port Gardner and Saratoga Passage. Specific boundary coordinates for each sampling site were provided by the U.S. Army Engineer District, Seattle. An overview of the study area is depicted in Figure 1. At the time of sampling, disposal site boundaries had not been finalized. Specific locations of benthic staions and trawl transects were therefore determined based on best available information on site boundaries, benthic and physical characterization data gathered during preliminary "checking studies", and previous fisheries resource surveys. Due to limits on the total sampling effort imposed by funding constraints, a decision was made to allocate sampling unequally among the four areas. This approach allowed a more detailed evaluation of selected sites on a prioritized basis. At the Commencement Bay, Elliott Bay, and Port Gardner study areas Primary (Site I)

and Alternative (Site II) Disposal Sites were identified (see Figures 2-4). At the Saratoga Passage study area only an Alternative Disposal Site was sampled (Figure 5).

5.   Box-coring and otter trawling efforts were conducted from the R/V Kittiwake, operated by the University of Washington. Field operations were conducted with the assistance of personnel representing the University of Washington, Battelle Laboratories (Pacific Northwest Division), the U.S. Army Engineer District, Seattle, and WES.

Benthic Sampling Design

Field Collection and Processing

6.   A total of 40 benthic samples were taken at the four sites, with sample allocation as follows: Commencement Bay - 8 impact stations (4 Primary and 4 Alternative) and 4 reference stations, Elliott Bay - 9 impact stations (5 Primary and 4 Alternative) and 5 reference stations, Port Gardner - 8 impact stations (5 Primary and 3 Alternative) and 2 reference stations, and Saratoga Passage - 3 impact stations and 1 reference station. A single reference station at the Elliott Bay Alternative Disposal Site was placed in a currently designated disposal site off the northwestern corner of the proposed site. Following the conclusion of field sampling, original disposal site boundaries were realigned by PSDDA Program management to incorporate new information on physical features and processes at these sites. This, however, had the effect of shifting several sampling stations out of the newly defined disposal sites. A single impact station was shifted slightly to the west of the Commencement Bay Primary Disposal Site. At Elliott Bay, shifting of the Primary Disposal Site boundaries resulted in the loss of one impact station and the concentration of the remaining impact stations in the western half of the Primary Disposal Site. Port Gardner and Saratoga Passage site boundaries were unaffected. Approximate station locations and spatial arrays are depicted in Figures 2-5. Locations of both benthic and trawl reference stations were selected based on comparability of a suite of physical parameters, including sediment type, as determined by results of prior "checking studies", as well as consistency with stations occupied by associated resource investigations (e.g., Dungeness crab population monitoring). An inventory of benthic sample station locations, including Loran coordinates and radar vectors, and water depths is given in Appendix A.

7.   Cores were collected by means of a 0.062 sq m Gray O'Hara stainless steel box-corer fitted with a plexiglass liner. As soon as the corer was retrieved and on deck, the liner containing the undisturbed sample was removed from the corer and processed as follows: Beginning at the sediment-water interface the core was divided into 0-2, 2-5, 5-10, and 10-15 cm vertical sections. The 0-2 cm section was washed into a 0.25 mm mesh seive bucket. The remaining vertical sections were individually washed into a 0.5 mm mesh sieve bucket. Each sediment sample was sieved by immersion of the buckets in a 30 gallon upright container filled with ambient seawater, and gently shaken and swirled to suspend the larger material and to allow fine sands, silts and clays to pass through the screens. Residual material was

placec in cloth bags that were pre-labelled internally and externally with an indelible marker, tied, and preserved in 10% seawater-buffered formalin The storage container and location of each bag was recorded on a field data sheet. All four vertically sectioned samples were then moved to the laboratory for analysis.

Laboratory Analyses - Benthic Cores

8.   Samples were picked and sorted to major taxa for each of the four vertical depth fractions (0-2, 2-5, 5-10, and 10-15 cm) from each box core ena were individually separated into discrete size class intervals by a wet sieving procedure as described by Carr and Adams (1973) and Sheridan (1979). Nested, graded 3-inch standard sieves used in the benthic analysis were; 6.35, 3.35, 2.0, 1.0, and 0.5 mm. The sieve series for processing the 0-2 cm depth fraction had one additional sieve with a 0.25 mm mesh size.   Each sample was processed as follows: the sample was carefully washed through the nested sieve series using a gentle water rinse, taking care not to damage soft-bodied benthic organisms. Each sieved sample starting with the 6.35 mm sieve and working down to the appropriate smallest mesh sieve was then vacuum filtered onto 0.45 micron cellulose acetate filters (millipore filter type HA), and next quantitatively transferred to weighing bottles.   Taxa sorted from the 0.25 mm sieved sample for the 0-2 cm depth fraction were weighed directly after filtering, as explained below. Wet-weight biomasses were initially recorded to 0.01 g and the sample returned to a properly labelled vial containing 70% alcohol.   In some isolated cases, when the available biomass was small, a higher level of accuracy was required (0.1 mg).

9.   For the 0-2 cm vertical depth fraction all individuals of each major taxon were enumerated.   Approximately 150 individuals of each major taxon were divided into 5 subsamples of 30 individuals each. Each subsample was weighed on an analytical balance to the nearest 0.001 mg.   Average individual weight for all five subsamples were then calculated as well as the standard deviation and coefficient of variation. The average individual weight was then used to estimate the total weight of that taxon in the sample by multiplying by the total number of individuals enumerated.

10.   Biomass data were converted to g/sq m (wet weights) and incorporated into the overall BRAT evaluation. All samples have been archived.

Fish Food Habits Sampling Design

Field Collection and Processing

11. A total of 27 otter trawl samples were obtained. Fish collections were conducted at each of the study sites concurrently with the benthic sampling. A 25-foot otter trawl was used to collect fish specimens. Sampling was allocated as follows: Commencement Bay - 6 impact trawls (3 Primary and 3 Alternative) and 2 reference trawls (1 shallow and 1 deep), Elliott Bay - 5 impact trawls (2 Primary and 3 Alternative) and 3 reference trawls, Port Gardner - 5 impact trawls (2 Primary and 3 Alternative) and 2 reference trawls, and Saratoga Passage - 3 impact trawls and 1 reference trawl.

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As stated above, original site boundaries for several disposal sites were altered following sampling. As a result, a single impact trawl fell slightly to the west of the Commencement Bay Primary Disposal Site. At the Elliott Bay Primary Disposal Site the final boundaries enclosed 3 rather than 2 trawl transects. Approximate locations of the trawl transects are noted in Figures 2-5.

12. Trawls were of relatively short duration in order to minimize deterioration and regurgitation of the gut contents. Target benthic feeding fish species representative of demersal fishes utilizing each site included the English sole (Parophrys vetulus), Dover sole (Microstomus pacificus), slender sole (Lyopsetta exilis), rex sole (Glyptocephalus zachirus), and flathead sole (Hippoglossoides elassodon). Fish collection efforts were directed by the number and composition of the catch at each study site. Fishes collected along each transect were processed as follows: (a) demersal bottom-feeding fishes were separated from pelagic fishes, which do not have value in the analysis, (b) the catch was sorted by species and each species was divided into Standard Length (SL) size classes of 5-9.9, 10-14.9, 15-19.9, 20-24.9, 25-29.9, and greater than 30 cm, (c) all individuals of the same species and size class captured at the same location were processed for food habits analysis according to the procedures described by Borgeson (1963). In brief, contents of multiple stomachs are dispersed into the same container with buffered 10% formalin. This procedure pools the variability between diets of individuals of the same species and size to yield a sample representative of the diet of an average individual feeding at a particular site. The procedure also preserves the integrity of individual food items that commonly become entangled and difficult to separate and identify when they are fixed within a fish's stomach as per more traditional techniques.

Laboratory Processing - Fish Food Habits

13. Stomach contents representing individual species size class samples were picked and sorted to major taxonomic categories (e.g., Mollusca, Annelida, Crustacea, etc.). Fish prey items were placed under the general category Nekton. Sorted-by-taxon samples were individually separated into discrete size class categories by a wet-sieving procedure described by Carr and Adams (1973) and Sheridan (1979). Wet-sieving was accomplished using a 3-inch diameter set of nested sieves from top to bottom in the following sequence: 6.35, 3.35, 2.0, 1.0, 0.5, 0.25, and 0.063 mm. In a manner similar to the treatment of the benthic samples, the stomach contents from each sieve were vacuum-filtered onto pre-weighed 0.45 micron cellulose acetate filters. This step stabilized the sample by removing free water. Wet-weights were recorded to the nearest 0.01g and the sample returned to a labelled container with 70% alcohol. Weights were tabulated by site, predator species, major taxon, and sieve size category. All samples have been preserved in 10% buffered formalin and archived.

Data Analysis

14. The data sets created by the field and laboratory efforts described above form the input to the BRAT evaluation. Based on examination of the fish food habits data, that component of the total benthic biomass that is

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both available and vulnerable to predation by the target fish species is estimated. This determination involves assignment of each fish size class sample to groups based upon their particular prey-size exploitation pattern. Percent biomass data were subjected to cluster analysis (numerical classification: Bray-Curtis similarity coefficient, group averaging sorting strategy) to objectively assign food habits samples, each representing a fish species-size class-location combination, to a feeding strategy group based on similarities in prey-size exploitation behavior. From the prey-size exploitation data, an estimate of the size range of prey utilized by, or vulnerable to given target predators is obtained. The stomach contents data are also used to estimate the foraging depth of each species size class sample. This is done by examination of the taxonomic composition of benthic prey in each food habits sample as compared to observations of the vertical distribution of prey taxa in the box-corer collections.

15. An examination of the raw benthic data indicated that large patches of biomass, particularly in the deeper sediment fractions, were contributed by Holothuroids and, rarely, Echinoids. These taxa, as evidenced by the stomach contents data, were not utilzed as prey items by any of the target fishes. Therefore, because their large biomasses would otherwise mask the importance of contributions made by the remaining benthic taxa, Holothuroid and Echinoid biomass data were deleted from the benthic data set.

16. For each cumulative (0-2, 0-5, 0-10, 0-15 cm) sediment depth fraction, size-partitioned biomass data for all non-deleted taxa were subjected to cluster analysis (Bray-Curtis similarity coefficient, square root transformation, group averaging sorting strategy) to assign benthic samples to groups or "strata" on the basis of their similarities in benthos-size distribution and relative biomass contribution. Patterns of high or low benthic biomass and size distribution can then be discerned when these data are superimposed on the spatial array of sampling stations.

17. Each benthic biomass stratum is then evaluated in terms of the potential trophic support afforded to each predator group. This step involves summation of the vulnerable (ie. appropriate size range) prey biomass from the sediment surface down to the lowest zone of prey availability (ie. foraging depth). Thus each benthic stratum is given a value in cumulative prey biomass (g/sq m) for each predator group. These values represent the potential prey biomass for target predator species, and allow comparative estimates of the trophic support afforded by different sampling sites to be made.

RESULTS

Box-Corer Samples

Field Observations

18. As stated in the Methods section, a total of forty box-corer samples was collected. Stations at Commencement Bay ranged in water depth from 169 to 178 m; at Elliott Bay from 61 to 169 m; at Port Gardner from 109 to 135

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m; at Saratoga Passage all stations were at 80 m.

19.   Visual inspection of box-corer samples indicated that sediments at all sampling sites were composed of relatively homogeneous silty-clays typical of depositional environments.   Exceptions were noted at Elliott Bay Alternative Disposal Site stations 1 and 2, where sediments contained a fairly high sand component.   These two stations lie in close proximity to the Fourmile Rock Disposal Site.   An obvious overburden of dredged material accounted for the anomolous sediment type at station 1.   At Port Gardner, a single station (Alternative station 10) showed a definite concentration of sandy sediments below a thin surface layer of silt-clay.   At Saratoga Passage, station 1 sediments consisted of very fine silts.

Taxonomic Composition of the Benthos

20.   In the BRAT analysis benthic samples are sorted only to major taxonomic categories.   Therefore a precise description of taxonomic composition at the family-species level cannot be given.   Examination of the changes in percent composition of major taxa among the study areas, however, does reveal some trends in the data.   Figure 6 illustrates these changes. Annelids and molluscs comprise the major components of the benthos at alomost all study areas (note, however, that Holothuroids and Echinoids have been excluded from consideration).   In terms of biomass, annelids generally dominate the benthos at all Commencement Bay sites, at Elliott Bay Primary and Reference Sites, and at Port Gardner Primary and Reference Sites. Visual inspection of the benthic samples indicated that polychaetes of the families Ophiliidae, Spionidae, and Maldanidae were important members of the infauna.   Molluscs, primarily bivalves of the genera Axinopsida and Macoma, were found at all study areas, but were dominant at both the Elliott Bay and Port Gardner Alternative Sites.   Annelids appear to be important members of the benthos at Saratoga Passage.   As explained below, however, this may be an artifact reflecting the very low biomasses of benthos collected at Saratoga Passage.   Crustaceans, largely mysids and mud shrimp, contribute generally less than ten percent to the mean biomass at any study area.

Spatial Distribution of Benthic Biomass

21.   Figure 7 depicts the mean biomass at stations within the various Primary, Alternative, and Reference areas.   Highest mean biomass per station was found at the Commencement Bay Alternative Disposal Site.   The lowest value occurred at the Saratoga Passage Reference Site (represented by a single station).   The depressed biomass values for the Saratoga Passage stations as a whole are evident in comparison with all other areas.   At Commencement Bay and Port Gardner, the Primary Disposal Sites displayed somewhat lower mean biomasses than their respective Alternative Disposal Sites.   This trend continued at the Elliott Bay sites also, but the difference between the Primary and Alternative Sites there was less notable.

22.   Vertical distribution of benthic biomass is summarized in Figure 8. Again, the exceedingly low biomass values at Saratoga Passage are readily apparent at all sediment depths.   The only substantial parcel of benthic biomass at Saratoga Passage occurs in the deepest sediment depth fraction,

which is beyond the foraging depth of most predators. The upper two cm of the sediment column, which is probably the most important from a trophic support standpoint, shows fairly consistent biomass levels among the remaining study areas, although Commencement Bay samples appear somewhat lower in comparison. Relatively high biomasses are found in the 0-2 cm depth fraction at both the Elliott Bay and Port Gardner Alternative Disposal Sites. In the 2-5 cm depth fraction, the Port Gardner Alternative Disposal Site continues to show a high biomass level, whereas the remaining Commencement Bay, Elliott Bay, and Port Gardner study areas are relatively uniform. The 5-10 cm sediment depth fraction displays the most variance in benthic biomass levels among study areas. Rather large pockets of biomass, approaching or greater than 25 g/sq m, are noted at the Commencement Bay Alternative and Reference Sites, as well as at the Elliott Bay Primary Reference Site. A depressed biomass value for this sediment depth fraction, similar to those levels at Saratoga Passage, occurs at the Elliott Bay Alternative Reference Site. Biomass values for the 10-15 cm sediment depth fraction are generally lower than at shallower depths and are variable. Fairly high concentrations of biomass continue to be found at the Commencement Bay Primary and Alternative Disposal Sites, and the Elliott Bay Primary Disposal and Reference Sites.

Size Composition of Benthic Biomass

23. Table 1 presents a compilation of the size-partitioned mean biomass values for major benthic taxa. This breakdown facilitates examination of the data for trends in the mean size of infaunal organisms among study areas. For example, a preponderance of small to intermediate sized benthos is indicative of opportunistic, newly recruited benthos, which characterize recently disturbed benthic communities. In contrast, the presence of larger benthic organisms can be indicative of long-term, stable, equilibrium communities. In this data set the biomasses of molluscs found at the Commencement Bay and Elliott Bay sites peak in an intermediate size range (1.0-2.0 mm), with the exception of the Elliott Bay Alternative Reference Site, where a large concentration of biomass occurs in the 6.35 mm size category. In contrast, the molluscs at the Port Gardner sites show peak biomasses in the 3.35 mm size category. Biomasses at the Saratoga Passage sites are too low to reveal a significant trend. Annelid biomass occurs primarily in the larger size categories (3.35-6.35 mm) throughout the Commencement Bay, Elliott Bay, and Port Gardner study areas. At Commencement Bay and Elliott Bay, however, very prominent biomass peaks occur in the 6.35 mm size category. At Port Gardner, the biomass is rather evenly distributed between the two largest size categories. Crustaceans at Commencement Bay sites are mostly intermediate in size, whereas they are somewhat larger at Elliott Bay sites. A mixed distribution, perhaps reflecting comparatively lower crustacean biomasses, is seen at Port Gardner. No distinct trends can be discerned for miscellaneous taxa among the study areas.

Benthic Strata

24. Benthic biomass data were clustered using size-partitioned and total biomasses as attributes for each station. Thus stations from different

study areas could, based on their similarity in biomass distribution, occur in the same cluster or stratum. Importantly, it should be noted that strata are formed independent of taxonomic composition. In this data set there appeared to be no remarkable differences among most stations in their size-partitioned biomass distribution. As a result, although biomass data were transformed prior to clustering, total biomass at a station was an important determinant of stratum composition. Spatial displays of the stations within a stratum can therefore be viewed as indicators of quantities of biomass present (Figures 9 through 12).

25. Based on the results of the cluster analysis, arbitrary biomass ranges were used to denote benthic strata. For the 0-2 cm sediment depth fraction Stratum A ranged from 0 to 5 g/sq m , Stratum B ranged from 5 to 10 g/sq m, Stratum C ranged from 10 to 18 g/sq m, and Stratum D contained greater than 18 g/sq m. For the 0-5 cm sediment depth fraction Stratum A ranged from 0 to 10 g/sq m, Stratum B ranged from 10 to 20 g/sq m, Stratum C ranged from 20 to 30 g/sq m, and Stratum D contained greater than 30 g/sq m. For the 0-10 cm sediment depth fraction Stratum A ranged from 0 to 15 g/sq m, Stratum B ranged from 15 to 30 g/sq m, Stratum C ranged from 30 to 60 g/sq m, and Stratum D contained greater than 60 g/sq m. For the 0-15 cm sediment depth fraction Stratum A ranged from 0 to 25 g/sq m, Stratum B ranged from 25 to 50 g/sq m, Stratum C ranged from 50 to 75 g/sq m, and Stratum D contained greater than 75 g/sq m. Where separate clusters consisted of stations of equivalent total biomasses, but different size categories, the additional strata were denoted by duplicate letters (eg., A, AA, AAA). Because the number of stations at each study area was limited, Strata A and B were pooled in Figures 9 through 12 to indicate areas of comparatively low biomass. Likewise, Strata C and D were pooled to indicate areas of high biomass. Demarcations between strata are arbitrary, but assist in visualizing trends in the spatial array of biomass data.

26. At Commencement Bay the surface (0-2 cm) sediment layer in the vicinity of the contiguous disposal sites consists a wide area of low biomass broken by a band (or perhaps patches) of high biomass running through the center of the Alternative Disposal Site in a north-south direction, and through the northeast quadrant of the Primary Disposal Site into the adjacent portion of the Reference Site (see Figure 9). A distinct shift to relatively high biomass levels is seen in the 0-5 cm sediment depth fraction, as only the two northernmost stations in the Reference Site and three stations forming the western side of the Alternative Disposal Site and upper portion of the Primary Disposal Site fall into low biomass strata. High biomass levels are generally maintained in the 0-10 cm sediment depth fraction, as an additional station in the Alternative Disposal Site joined the high biomass strata. This general pattern continues down into the 0-15 cm sediment depth fraction, except for reduced biomass at an additional station in the Primary Disposal Site.

27. At Elliott Bay the Primary Disposal Site is characterized by high biomass strata in the 0-2 cm sediment depth fraction, with an area of low biomass intruding into the site boundary from the west (see Figure 10). The lack of stations in the eastern portion of the site, due to the shift in site boundaries after completion of sampling, hinders interpretation of the

observed pattern. However, the area of depressed biomass in the upper sediment layer may reflect the effects of a disposal site capping project conducted in this general area. In the 0-5 cm sediment depth fraction high biomass stations are restricted to the southernmost stations. In the deeper cumulative sediment depth fractions the comparative biomasses are shifted to low levels, with high biomass persisting southeast of the Primary Disposal Site. At the Alternative Disposal Site high biomass levels predominate in the 0-2, 0-5, and 0-10 cm sediment depth fractions. A single station (EB-AD-3) in the Alternative Disposal Site shows low biomass levels at these depths. A general shift to low biomass levels occurs for the 0-15 cm sediment depth fraction at this site.

28.   The Port Gardner Primary Disposal Site is characterized b. high biomass levels in much of the 0-2 and 0-5 cm sediment depth fractions (see Figure 11). A single station (PG-PD-2) exhibited low biomass in both depth fractions. In the 0-10 and 0-15 cm sediment depth fractions at this site, a gradual shift to lower biomass levels is seen, first in the western portion of the site in the 0-10 cm fraction, and throughout the 0-15 cm fraction. The Alternative Disposal Site displays high biomass levels throughout the 0-2, 0-5, and 0-10 cm sediment depth fractions. In the deepest fraction the southernmost, inshore station (PG-AD-10) shifts to a lower biomass level.

29.   Saratoga Passage shows complete uniformity in biomass levels, with all stations in all sediment depth fractions falling into the lowest biomass stratum (Figure 12).

Summary of Benthic Biomass Distribution

30.   Figures 13-22 are three-dimensional plots of benthic biomass across size categories and sediment depth intervals. Individual figures present biomass distribution at a given disposal or reference site (stations pooled). For example, Figure 13 depicts vertical distribution of benthic biomass at the Elliott Bay Primary Disposal Site. A pattern of large benthic particles occurring at the deeper sediment depths is revealed. In the uppermost sediment depth fraction, benthic biomass occurs predominantly in the 1.00 mm size category. This basic pattern persists, with some variation, at all of the study sites, indicating fundamental similarity in benthic community conditions. The occurrence of large benthic organisms deep in the sediment is indicative of late successional stage communities. A predominance of very small benthos confined to the surficial sediments would, in contrast, be indicative of opportunistic, early successional stage communities.

Fish Food Habits Samples

Field Observations

31.   A total of 22 species-size class samples (meeting an arbitrary criterion of at least three stomachs containing identifiable material per sample) were used in the analysis. Additional species were represented in the trawl catch, but not in sufficient numbers in a given size class to justify inclusion. Among these 22 species-size classes a total of 244

individual stomachs was distributed (Table 2). Sample size was unequal among species and study areas, generally reflecting the composition of the catch at the respective study areas. For example, slender sole was the most abundant species captured, although insufficient numbers were taken at Commencement Bay to comprise a sample. In contrast, Dover sole ranked second in abundance in the catch, but were not present in sufficient numbers to form a species-size class at Saratoga Passage. English sole were present at Commencement Bay and Port Gardner, but not captured elsewhere. Flathead sole and rex sole were taken in small numbers at Elliott Bay, and Commencement Bay and Elliott Bay respectively. The largest catch (121 fish) was taken at Elliott Bay, whereas both Commencement Bay and Saratoga Passage are represented by substantially smaller catches. Dover sole and English sole were represented in the catch by relatively larger size classes (greater than 20 cm SL).

32. Despite the fairly deep water depths along some of the trawl transects, the general condition of the stomach contents was good, as indicated by the low biomass percentages of unidentifiable food items. A single species-size class sample (10-15 cm rex sole from the Commencement Bay Shallow Reference Site) contained an inordinate amount of unidentifiable material, and was considered meaningless in interpretation of the results.

Species Accounts - Taxonomic Composition of the Diets

33. The food habits data for each species are discussed below. Recognition should be given to the fact that sample size for several target species is limited, and to the single season coverage of the samples. Thus the results reflect a "snapshot" of the feeding behavior of these species, and not a comprehensive picture of their biology. Figure 23 displays the taxonomic composition of the diets on a percent biomass basis.

(a) Slender Sole (*Lyopsetta exilis*) - The diets of slender sole in the 5-9.9 and 10-14.9 cm SL size classes consisted largely of mysids, which are probably taken epibenthically or in the water column just above the bottom. Some indication of predation on infauna was evidenced by small percentages of nematodes, amphipods, and polychaetes. One 10-15 cm SL sample taken at the Elliott Bay Alternative Disposal Site had eaten decapods almost exclusively. Slender sole in the 15-20 cm SL size class were somewhat more diversified in prey items. Mysids and decapods comprised most of the diets, but copepods, bivalves, polychaetes, amphipods, and nematodes were also present. These data are consistent with previously reported food habits for this species. Pearcy and Hancock (1978) found that off the Oregon coast slender sole were captured most frequently at deep, soft-bottom stations. In their samples slender sole had fed primarily on pelagic crustaceans, including euphausiids, shrimps, and amphipods. Annelids comprised 15.6 percent of the diet, whereas molluscs were present only in trace amounts. The moderate sized mouth gape and large eyes are morphological features of this species that fit a feeding strategy for utilization of active, mobile prey.

(b) Dover Sole (*Microstomus pacificus*) - In contrast with the slender sole, Dover sole display the classic morphological features of an infaunal-

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feeding flatfish. The terminally placed mouth is asymmetrical, facilitating downward orientation during feeding, and has a small gape. In the study by Pearcy and Hancock (1978), Dover sole fed predominantly on annelids (64.4 percent by weight) and secondarily on molluscs (18.3 percent) and crustaceans (11.2 percent). They reported that Dover sole were opportunistic feeders, as the diet varied with sediment type. Their catch of Dover sole on the Oregon coast was positively correlated with the abundance of polychaetes in grab samples. In a study of resource partitioning among a guild of flatfishes in central Puget Sound, Becker (1984a) observed that Dover sole preferred deeper (32 m), muddy nearshore habitats, and were primarily diurnal feeders. Polychaetes were a major food item (approximately 58 percent by abundance), followed by crustaceans and molluscs (approximately 30 and 13 percent respectively). In a separate study of flatfishes taken from the delta of the Puyallup River in lower Commencement Bay, Becker (1984b) reported that Dover sole diets consisted of 63.1 percent (relative abundance) annelids, 22.5 percent crustaceans, and 14.4 percent molluscs. The abundance of Dover sole increased along a pollution gradient created by effects of municipal wastewater effluent near Los Angeles, California (Cross et al., 1985). In a manner similar to that reported by Pearcy and Hancock (1978), the abundance of Dover sole paralleled the increasing abundance of polychaetes in the sediments along the gradient. This was reflected in their diets as polychaetes became more important prey components. Crustacea showed an opposite trend of decreasing abundance along the gradient, both in the grab samples and in the stomach contents samples. Gabriel (1981) investigated factors determining feeding selectivity by Dover sole on the Oregon continental shelf. She noted that polychaetes and ophiuroids were more important prey items in terms of weight, numbers, and frequency of occurrence than molluscs or crustaceans. In the present study, most Dover sole size class samples fed largely on annelids. Bivalves were also important, particularly for larger size classes (25-29.9 and 30-34.9 cm SL) at the Port Gardner Alternative Disposal Site. A single size class sample (25-29.9 cm SL) at the Commencement Bay Alternative Disposal Site had eaten decapods almost exclusively. Dover sole taken from the Elliott Bay Alternative Disposal Site exhibited comparatively high diversity of stomach contents, including mysids, amphipods, cumaceans, isopods, and ostracods in appreciable amounts.

(c) English Sole (Parophrys vetulus) - This species also shows the morphological features characteristic of an infaunal-feeder. A number of studies have reported the food habits of this flatfish (Kravitz et al., 1976; Hulberg and Oliver, 1979; Becker, 1984a,b; Cross et al., 1985). Notable food items include bivalve siphons, polychaetes, small crabs and shrimps, and brittle stars. Samples collected by Becker (1984a) in central Puget Sound had diets consisting mainly of polychaetes (over 70 percent by abundance), molluscs (about 18 percent), and crustaceans (about 10 percent). Becker's (1984b) samples from the Commencement Bay area had eaten primarily polychaetes (84.4 percent relative abundance) and molluscs (14.0 percent). English sole showed the same changes in abundance and diet along a pollution gradient as did the Dover sole in the study by Cross et al. (1985) described above. In the present study samples of English sole were obtained only at Commencement Bay and Port Gardner. At Commencement Bay, fish in the 20-24.9 cm SL size class had preyed mainly on polychaetes, with bivalves forming a

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smaller portion of the diet. The same size class at the Port Gardner Primary Disposal Site had a similar diet, with the addition of urochordates. In contrast, two samples at the Port Gardner Alternative Disposal Site had fed primarily on bivalves.

(d) Flathead Sole (_Hippoglossoides elassodon_) - Flathead sole, having a relatively large mouth gape, display a feeding strategy similar to that of the slender sole. Miller (1970) documented the diet of flathead soles taken in northern Puget Sound. In terms of percent weight, mysids and shrimps were the most important food item (51.2 percent), followed by fishes (38.6 percent), bivalves (5.8 percent), and polychaetes (2.8 percent). In the present study samples of flathead sole were obtained only at Elliott Bay in or adjacent to the Primary Disposal Site. The smallest size class (10-14.9 cm SL) had a high proportion of nematodes in their stomachs, with mysids and amphipods being of secondary importance. Fish in the 15-19.9 cm SL size class had stomach contents which varied greatly among samples, but were dominated by decapods, fishes, and/or bivalves.

(e) Rex Sole (_Glyptocephalus zachirus_) - The rex sole is another small-mouthed flatfish. Pearcy and Hancock (1978) reported that rex sole smaller than 15 cm SL fed primarily on amphipods and other crustaceans, whereas larger rex sole shifted their diets to mainly polychaetes. In the Gulf of Alaska rex sole (12-26 cm) were found by Smith et al. (1978) to eat mainly polychaetes (54.6 percent by weight), followed by pandalid shrimp, small crabs, euphausiids, and pelecypods. Rex sole collected in central Puget Sound by Becker (1984a) had stomach contents consisting almost entirely of polychaetes. His samples contained fish in the 21-29 cm Total Length (TL) size range. At Commencement Bay, Becker (1984b) determined that rex sole had also eaten primarily polychaetes (over 96 percent relative abundance). In the present study only two samples of rex sole were obtained. One sample taken at Commencement Bay contained largely unidentifiable digested material. A sample (5-9.9 cm SL) from the Elliott Bay Primary Disposal Site had eaten decapods, copepods, and amphipods.

34. These data indicate that for the purposes of the BRAT analysis, the samples of Dover and English soles are of primary interest due to their demonstrated reliance on infaunal prey items.

Fish Prey Size Feeding Strategies

35. The results of cluster analysis (see Appendix) and graphical treatment of the food habits biomass data were used to classify species and size classes into prey size feeding strategy groups that are described in Table 3. Figures 24 through 30 are displays of the prey size exploitation patterns of these feeding strategy groups. In sequence the figures show a gradual shift in prey size preference from small to large prey, with Group IIIB predators utilizing the larger prey size categories almost exclusively. Table 4 lists the fish species and size classes assigned to each group. Note that in a number of instances the same size class of the same fish species exhibits a different feeding strategy. For example, English sole representing the 25-29.9 cm SL size class from the Port Gardner Alternative Disposal Site and Reference Site fall into Groups IIIA and IIB respectively.

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Another example is seen with Dover sole in the 30-34.9 cm size class. Samples from the Commencement Bay Alternative Disposal and deep Reference Sites sorted together in Group IIB, whereas at the Port Gardner Alternative Disposal Site the sample fell into Group IIC, and at the Elliott Bay Alternative Disposal Site into Group IIIA. Given the caveat that sample sizes are fairly small, this may be an indication that slight qualitative differences in the prey available to these bottom feeders exist at the various sites. Composition of several groups show a substantial degree of species integrity. For example, slender sole samples form much of Group IIIA. Dover sole samples form most of Group IIC.

36. Observed differences in prey size exploitation patterns by the same species and size class captured from two locations, however slight, lead to questions regarding feeding efficiency. Data on the weight of each fish food habits sample and the number of stomachs that comprised each pooled sample (given in Appendix) were used to calculate the mean weight of food in each sample (Table 5). These calculations indicate that although feeding efficiency was on the whole low (ie., small amounts of biomass per stomach), substantial differences in feeding efficiencies among the study areas are not apparent. For example, slender sole caught at Saratoga Passage, where benthic biomasses were exceedingly low, do not show feeding efficiencies dramatically lower that slender sole from Elliott Bay. Large Dover sole at Elliott Bay do show comparatively higher efficiencies than the same size classes at either Commencement Bay or Port Gardner, but the pattern does not hold for smaller size classes.

Benthic Resource Value Analysis

Computation of Benthic Resource Value

37. Cumulative benthic biomass within the various sediment depth fractions for each benthic stratum forms the basic input into the resource value computations. These data are presented in Table 6. For each stratum a determination of that portion of the total benthic biomass that is both vulnerable and available to predation is made. Those portions of the total biomass determined to be either too small or too large to fit a predator group's feeding strategy (not vulnerable) or beyond that predator group's foraging depth (not available) are deleted from the appropriate stratum's total biomass. Recall that large parcels of echinoid and holothuroid biomass, which do not represent prey items, have already been removed from the data set.

38. Comparison of the taxonomic composition of the diets of fish size class samples in each predator feeding strategy group reveals that in several cases a group consists partially or mainly of epibenthic rather than infaunal feeders. Groups which contain no evidence of infaunal feeding (i.e., Groups II, IID, and IIIB) are logically of little importance in assigning a value to the benthos as trophic support. Therefore, these groups receive no further consideration in the analysis. Group's IIA, IIB, IIC, and IIIA, however, do contain fish size class samples that have utilized infaunal prey items and are treated below.

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39. First, an estimate is made of the size range of prey showing significant exploitation by a given predator group. For example, from Figure 24, it can be seen that prey size categories between 0.25 and 2.00 mm contribute at least ten percent to the overall diet of Group IIA predators. Likewise, for Group IIB predators prey between 0.50 and 3.35 mm are major dietary contributors (Figure 26). In the case of Group IIA predators prey biomass in the appropriate benthic strata larger than 2.00 mm will be considered to be outside of the vulnerable range size. For Group IIB predators, prey smaller than 0.5 mm and larger than 3.35 mm will be considered outside of the vulnerable size range.

40. Next, a determination is made of the foraging depth of the selected predator groups. This is the most subjective step in the overall analysis, and requires extensive investigation of the data sets. For example, if polychaetes are the major prey taxon of a particular predator group, examination of the vertical distribution of polychaete biomass in the sediments at stations adjacent to the trawl transects from which the fish samples were captured can provide insight into the probable foraging depth of those fishes. If the major concentration of polychaete biomass lies between 2 and 5 cm, then a conclusion can be reached that the fishes are exploiting the 0-5 cm sediment depth fraction. If the polychaete biomass accumulates in a linear fashion with sediment depth down to 15 cm, then best available information on the feeding behavior of a given species must be relied upon. For example, Gabriel (1981) reported that only large size classes of Dover sole foraged deeper than 2 cm into the sediment. This approach, however, must consider the behavior of the specific prey items. Many species of polychaetes which build tubes deep into the sediment are surface deposit-feeders. Although fish are able to crop the exposed portions of the annelids at the sediment surface, the biomass for these polychaetes may actually be found quite deep in the box-corer samples. During sampling these and other annelids might be expected to retract downward into their tubes. Based on considerations such as these, an estimated foraging depth for each predator group is reached.

41. The results of the benthic resource computations are presented in Tables 7 through 10. For Group IIA predators, which include several smaller size class samples of Dover sole, a 5 cm foraging depth was used (Table 7). From the total biomass in the 0-5 cm sediment depth available zone, as depicted in Figure 31, that portion determined to be outside of the vulnerable range is removed. This operation is repeated for each 0-5 cm benthic stratum. The biomass remaining in each stratum is then a measure of the potential biomass that can be utilized by Group IIA predators at stations in that respective stratum. In establishing biomass criteria for the benthic strata, a progression from very low biomass in Stratum A to very high biomass in Stratum D was created. However, the resource analysis for Group IIA predators indicates that, for this group of predators, Stratum B (13.6 g/sq m) contained a greater potential food resource than Stratum CC (9.7 g/sq m). An overall pattern of rough equivalence of potential food value among strata existed, with the exception of Stratum A, which yielded very little food value.

42. Group IIB predators included a number of size class samples of larger

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Dover sole and three of five English sole samples. For this group a 10 cm foraging depth was used (Table 8). For benthic Strata A, B, and BB food resource values are comparable to those calculated for Group IIA predators for a shallower foraging depth. Strata C, CC, and D show substantially elevated potential food resources for Group IIB predators in comparison with Group IIA.

43. Group IIC predators, representing a range of Dover sole size class samples and a single English sole sample, were assigned a 5 cm foraging depth (Table 9). Resource values exhibited a pattern of low potential food value in Stratum A, moderate food values in Strata B, BB, and CC, and relatively high food values in Strata C and D.

44. Group IIIA predators, represented by a number of samples in which epibenthic predation was probably important (although large Dover sole were included), were assigned a 10 cm foraging depth (Table 10). Figure 32 depicts the total size-partitioned benthic biomass in the various strata in the 0-10 cm sediment depth available zone. Resource values for these predators were generally low except for Strata C and D. Stratum D represented the highest potential food value (72.5 g/sq m) calculated in the study.

45. Figure 33 summarizes the estimates of trophic support potential for each benthic biomass stratum across predator feeding groups. The pattern that emerges is complex, with a number of deviations from a general trend for increasing trophic support with increasing total benthic biomass. Stratum A provides minimal trophic support for any feeding group. Groups IIB and IIC derive substantial potential trophic support from Strata B, BB, C, CC, and D, whereas Group IIIA predators are primarily benefited by Strata C and D.

CONCLUSIONS

46. A fundamental question faced by resource managers in the PSSDA Program is, "What open-water dredged material disposal plan is optimal with regard to logistical, economic, and environmental considerations?" Sampling effort in the present study was directed at providing insight into the environmental realm of this complex question. The study addresses the more specific question, "What are the comparative benthic habitat qualities of the proposed Primary and Alternative Disposal Sites in terms of potential trophic support for bottom-feeding fishes?"

47. An initial statement of the limits of the data is required. Because the data represent a single summer sampling effort, extrapolation of the results to a complete seasonal cycle is impossible. However, the data do adequately describe conditions at the project sites during a period when benthos are actively being exploited by resident fish populations. A second limitation of the data is that sampling effort was unequal among study areas such that not all target species were sampled at each site. This reflects in part variation in the habitat preferences of the selected target species. Sufficient data were obtained to reach conclusions regarding key target

species, namely Dover sole and English sole. At the time of sampling, populations of slender sole, flathead sole, and rex sole were present at several study areas. These flatfish species, however, were preying heavily on non-infaunal organisms. Mysids in particular appeared to be abundant at both Saratoga Passage and Elliott Bay, as evidenced by the proportions of this taxon in the fish food habits samples. During those times when mysids and other epibenthic prey become less available, these predator species probably become more dependent upon infaunal prey.

48. The most remarkable difference between study areas observed in the data is the substantially depressed benthic biomass found at Saratoga Passage. There are several possible explanations for this condition, although without additional data each is speculative. Saratoga Passage, the northernmost of the four study areas, has historically supported an intensive commercial fishery for bottom fishes. Extensive trawling in the study area immediately prior to sampling could account for some reduction in benthic biomass as a result of physical disturbance of the surficial sediment layers. A second hypothesis is that the depressed standing stock of benthic biomass is the result of an hypoxic event such as seasonally occurs in the Chesapeake Bay and other coastal waters. The author is unaware of any existing information on dissolved oxygen concentrations in bottom waters at Saratoga Passage. A third hypothesis is that intense predation pressure has resulted in the observed low benthic biomass. The rather low trawl catches at the Saratoga Passage sampling sites tends to refute this third explanation.

49. There were no sharp differences in the overall vertical distribution of major benthos taxonomic categories among the Commencement Bay, Elliott Bay, and Port Gardner study areas. Likewise, the size distributions of benthos were essentially similar at these areas. Due to the underlying similarities in size distributions, the benthic strata defined in the analysis largely reflect differences in total biomass. Examination of Figures 9 through 12, although subject to loose interpretation due to the constraints of sample size, generally indicate consistent patterns in the spatial distribution of benthic biomass through the cumulative sediment depth fractions.

50. At Commencement Bay, the Alternative Disposal Site appears to represent "better" foraging habitat for small size classes of Dover sole and English sole than the Primary Disposal Site. This is based on the presence of high biomass at two of the four Alternative Site 0-2 cm stations, whereas the three Primary Site 0-2 cm stations possess lower benthic biomasses. Biomass distribution in the 0-5 cm sediment depth is less biased toward either site. At both the 0-5 and 0-10 cm levels, however, at least one station in the Alternative Disposal Site falls in the very high biomass, high food value Stratum D.

51. At Elliott Bay, the choice between Primary and Alternative Disposal Sites is somewhat easier. Three of four stations in the Alternative Disposal Site maintain high benthic biomass and high potential food value down to the 10 cm sediment depth level. At the Primary Disposal Sites both high biomass and high food value become restricted to the inshore portion of the site with increasing sediment depth.

52.   At Port Gardner the Alternative Disposal Site also appears to offer higher trophic resource potential than the Primary Disposal Site.   High biomass and food value are maintained at all three Alternative stations down to the 10 cm sediment depth level, whereas evidence of lower benthic biomass and food value occurs in a portion of the Primary stations.

53.   In summary, although major differences in benthic habitat quality were not demonstrated among the Commencement Bay, Elliott Bay, and Port Gardner Primary and Alternative Disposal Sites, slight indications of enhanced trophic support potential at the respective Alternative Sites would lend support to their exclusion as operational disposal sites.   Benthic habitat quality conditions at the Saratoga Passage study area are enigmatic, and would require additional study to illucidate.

EXECUTIVE SUMMARY

54.   A Benthic Resources Assessment Technique evaluation of proposed open-water dredged material disposal sites in Puget Sound, Washington was performed. The evaluation, based on samples taken in June and July, 1986 at four study areas (Commencement Bay, Elliott Bay, Port Gardner, and Saratoga Passage), provides comparative assessments of benthic habitat quality at the study areas in terms of potential trophic support for bottom-feeding fishes. The results of this study are particularly relevant to utilization of the proposed sites by Dover and English soles.   Major findings of the study are outlined below.

A.   Taxonomic composition (at the Order level) of the benthos was essentially similar among all study sites. Polychaetes dominated the benthos at all Commencement Bay Sites, at Elliott Bay Primary and Reference Sites, and at Port Gardner Primary and Reference Sites. Bivalve molluscs were dominant at both the Elliott Bay and Port Gardner Alternative Sites.

B.   With regard to total benthic biomass, Alternative Sites at Commencement Bay, Elliott Bay, and Port Gardner had consistently higher standing crops of benthos than the respective Primary Sites (although the absolute differences were not striking). Saratoga Passage displayed uniformly low benthic biomass values.

C.   Vertical distribution of benthic biomass in the sediment column down to 15 cm was quite similar among all Commencement Bay, Elliott Bay, and Port Gardner sites.   Relatively high biomass values were found for the uppermost (0-2 cm) sediment depth zone at both the Elliott Bay and Port Gardner Alternative Disposal Sites.

D.   Estimates of trophic support potential generally corresponded with total benthic biomass measurements at the various study sites. Benthic strata comprising the Commencement Bay, Elliott Bay, and Port Gardner Alternative Disposal Sites represented slightly higher quality fish feeding habitat than the respective Primary Disposal Sites.

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55.   Based on the results of the BRAT evaluation, it is the recommendation of the Coastal Ecology Group, WES that the Primary Disposa) Sites at Commencement Bay, Elliott Bay, and Port Gardner be designated as operational open-water disposal sites. From a resource perspective, the Alternative Sites (with the exception of Saratoga Passage as noted above) have slightly higher functional values for bottom-feeding fishes. Although additional sampling, especially on a seasonal basis, would be required to determine absolute differences in benthic habitat quality at the study sites, the preponderance of available evidence supports the above recommendation.

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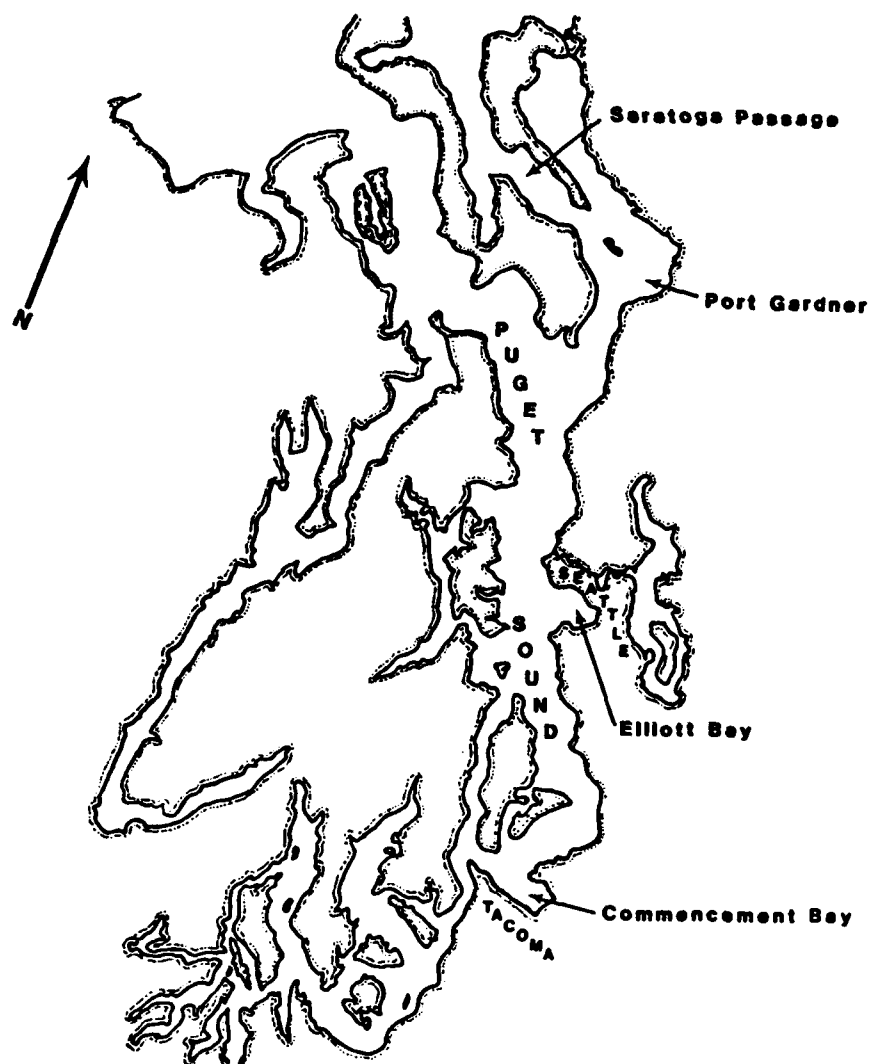
Figure 1. Overview of study areas in Puget Sound, Washington.

Figure 2. Sampling locations at Commencement Bay, Washington. Inset shows area in Puget Sound corresponding to detail in *Figure 1. Approximate* boundaries of the Primary (Site I) and Alternative (Site II) Disposal Sites indicated with respective benthic (PD, AD) and trawl (T) stations noted. Reference stations denoted by RA, DR, and SR.

SITE II

SITE I

COMMENCEMENT BAY

BROWN'S POINT

OLD TACOMA

• CB-RA-1

• CB-RA-2

• CB-RA-3

• CB-RA-4

T-SR

T-DR

• CB-AD-1

T-3

• CB-AD-2

T-2

• CB-AD-3

T-1

CB-AD-4

CB-PD-5

T-7

T-6

• CB-PD-6

• CB-PD-8

• CB-PD-7

T-5

SCALE

0   1 MI

1
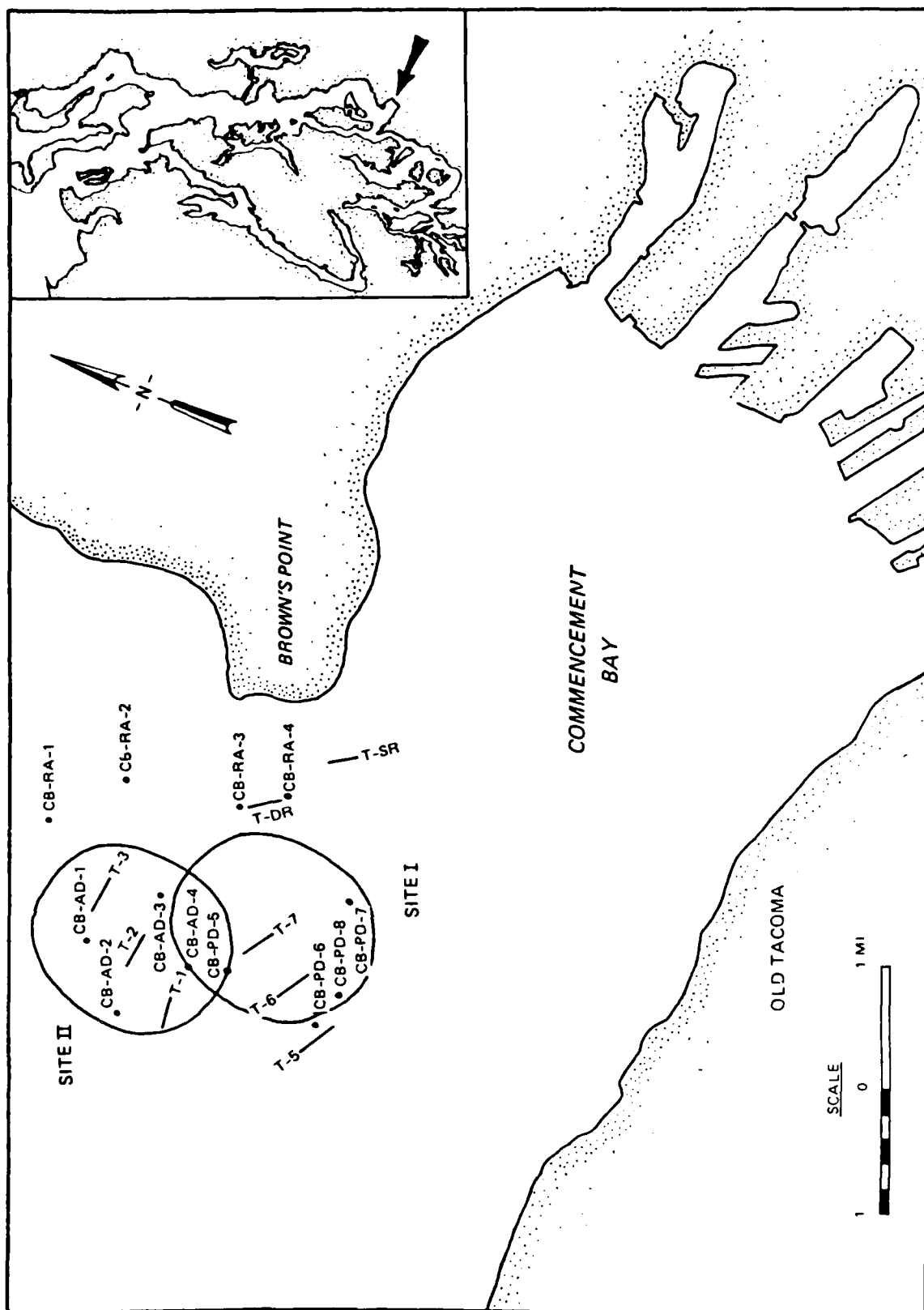
Figure 3. Sampling locations at Elliott Bay, Washington.
Inset shows area in Puget Sound corresponding to
detail in Figure 1. Approximate *boundaries of*
Primary (Site I) and Alternative (Site II) Disposal
Sites indicated with respective benthic (PD, AD)
and trawl (T) stations noted. Reference stations
denoted by AR and PR, with exceptions as explained
in text.

SITE II
EB-AD-1
EB-AR-1
T-1
EB-AD-3
T-2
EB-AD-2
T-3
EB-AB-4
EB-AR-2 T-4
EB-AD-5
FOURMILE ROCK

ELLIOTT BAY

SEATTLE

SITE I
T-8
EB-PD-3
EB-PD-7
T-6
EB-PD-8
EB-PD-10
T-5
EB-PR-6
T-7
EB-PR-9
EB-PD-4

DUWAMISH HEAD

HARBOR ISLAND

N

SCALE
1   0   1 MI

25
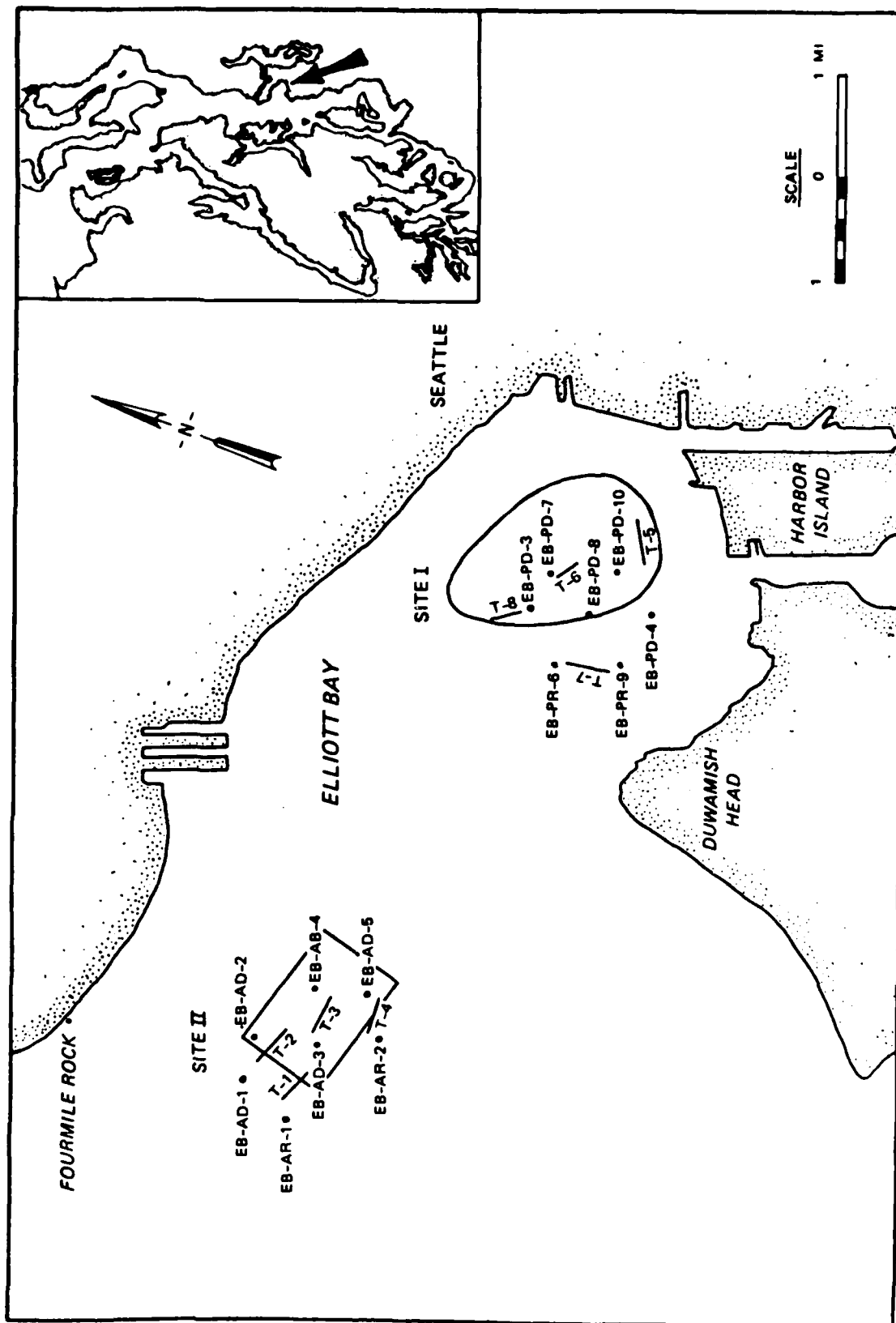
Figure 4. Sampling locations at Port Gardner, Washington.
Inset shows area in Puget Sound corresponding to
detail in Figure 1. Approximate boundaries of
Primary (Site I) and Alternative (Site II)
Disposal Sites indicated, with respective benthic
(PD, AD) and trawl (T) stations denoted. Reference
stations denoted as RA.

EVERETT

PORT
GARDNER

SITE II

T-6
PG-AD-9 •
T-5 •
• T-4
PG-AD-10

PG-PD-3

PG-PD-4 •
• T-1
PG-PD-6

SITE I

T-2
• PG-PD-2
PG-RA-1 • T-3
PG-PD-5

PG-AD-8 •
PG-RA-7 • T-7

N

SCALE

0   1 MI
1

GEDNEY
ISLAND

27
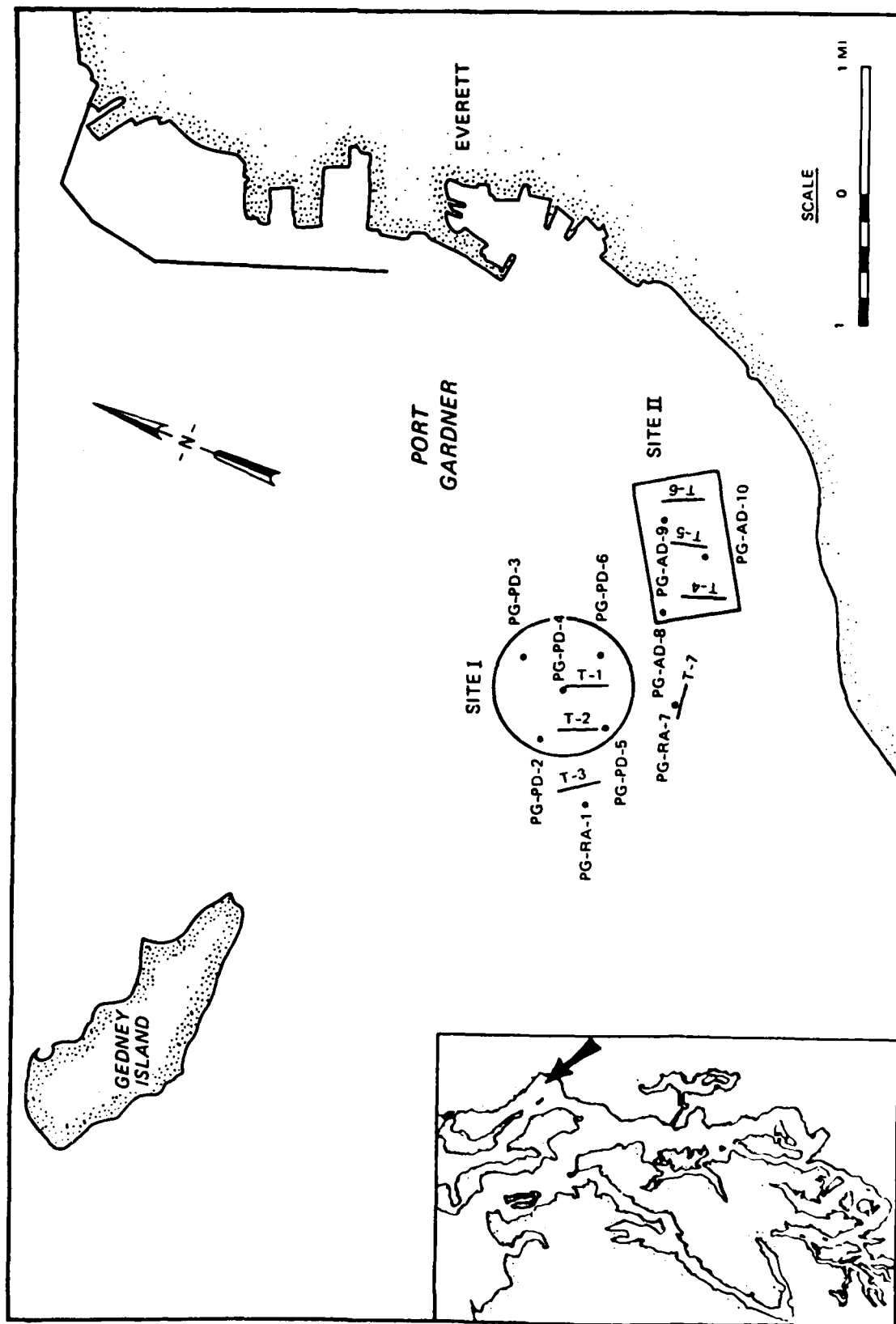
Figure 5. Sampling locations at Saratoga Passage, Washington. Inset shows area in Puget Sound corresponding to detail in Figure 1. Approximate boundaries of Alternative Disposal Site indicated, with benthic (AD) and trawl (T) stations noted. Reference station denoted by RA.

CAMANO ISLAND

LOWELL POINT

EAST POINT

SP-PD-1

SP-PD-2

T-2 T-1

SP-PD-3

SP-RA-4 T-3

T-4

SARATOGA PASSAGE

WHIDBEY ISLAND

BENTHOS TAXANOMIC COMPOSITION, % BIOMASS
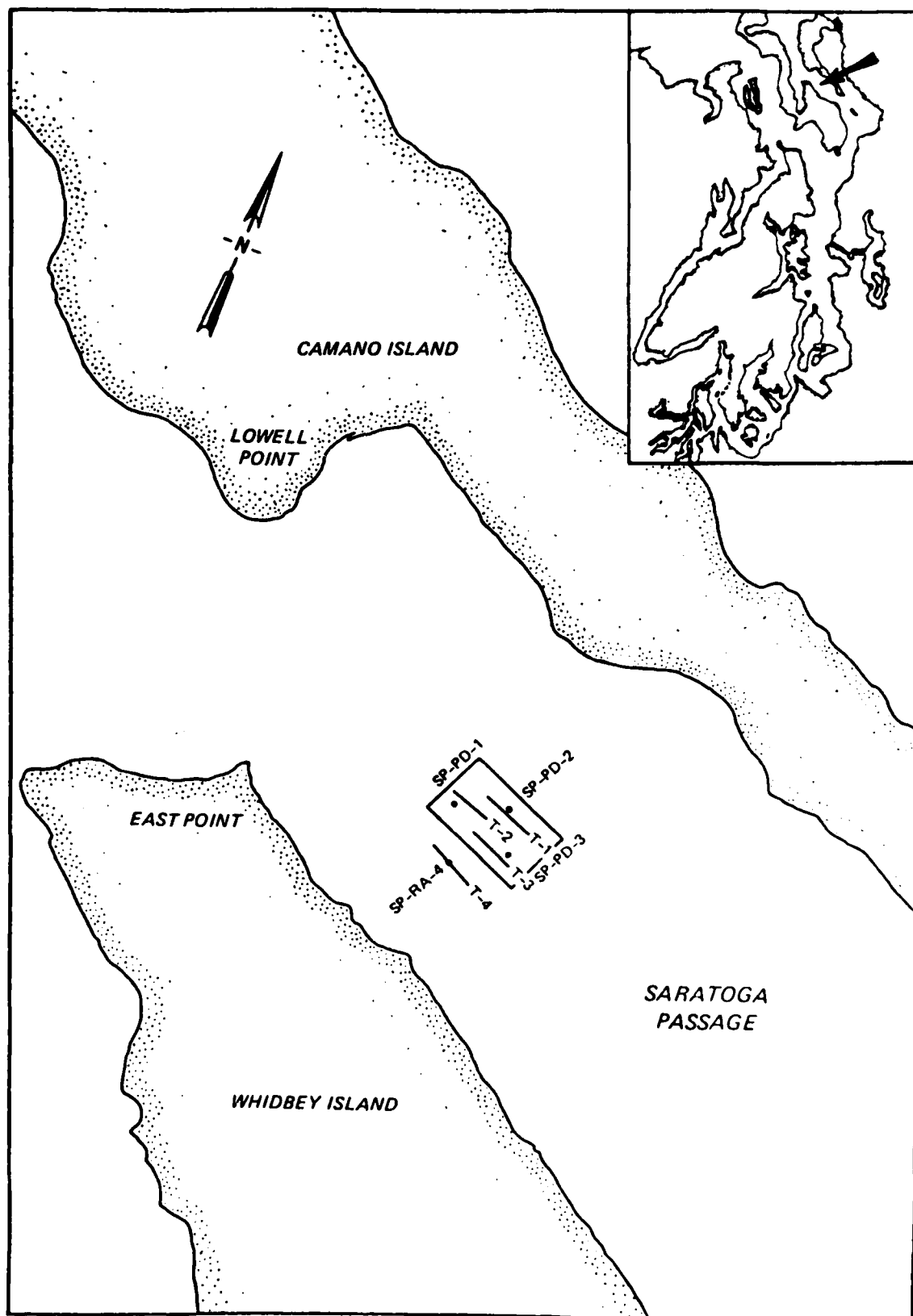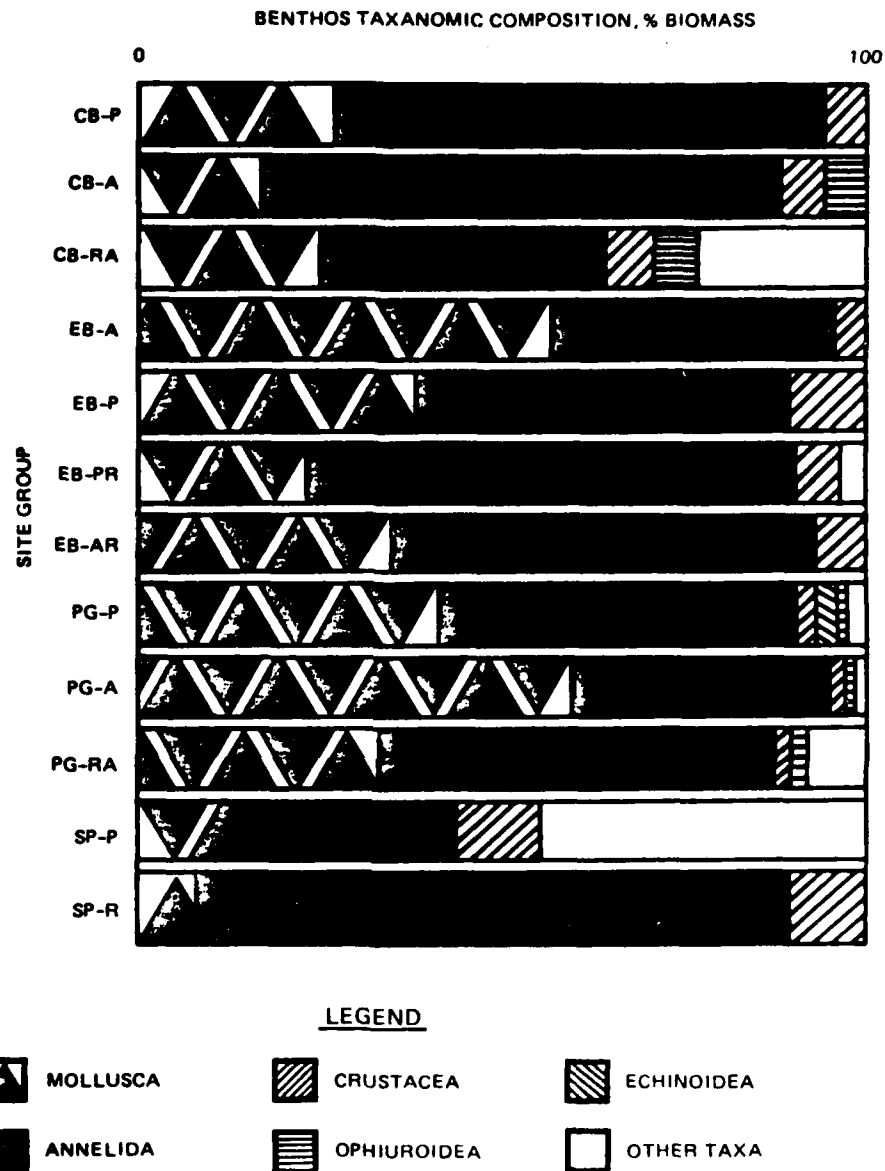
Figure 6. Taxonomic composition of benthos (large echinoids and holothuroids excluded) among the Puget Sound study areas. CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage, P = Primary Site, A = Alternative Site, RA = Reference Area, PR = Primary Reference, AR = Alternative Reference.
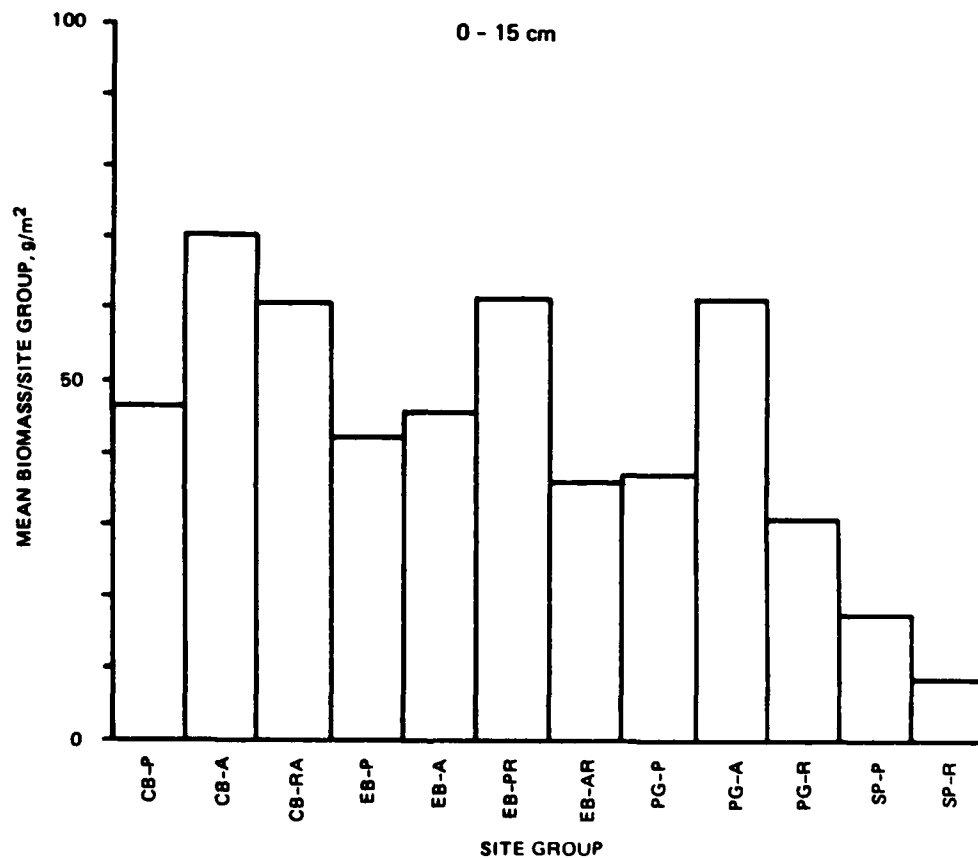
Figure 7. Distribution of mean benthic biomass among stations at each Puget Sound study area. CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage, P = Primary Disposal Site, A = Alternative Disposal Site, RA = Reference Area, PR = Primary Reference, AR = Alternative Reference.

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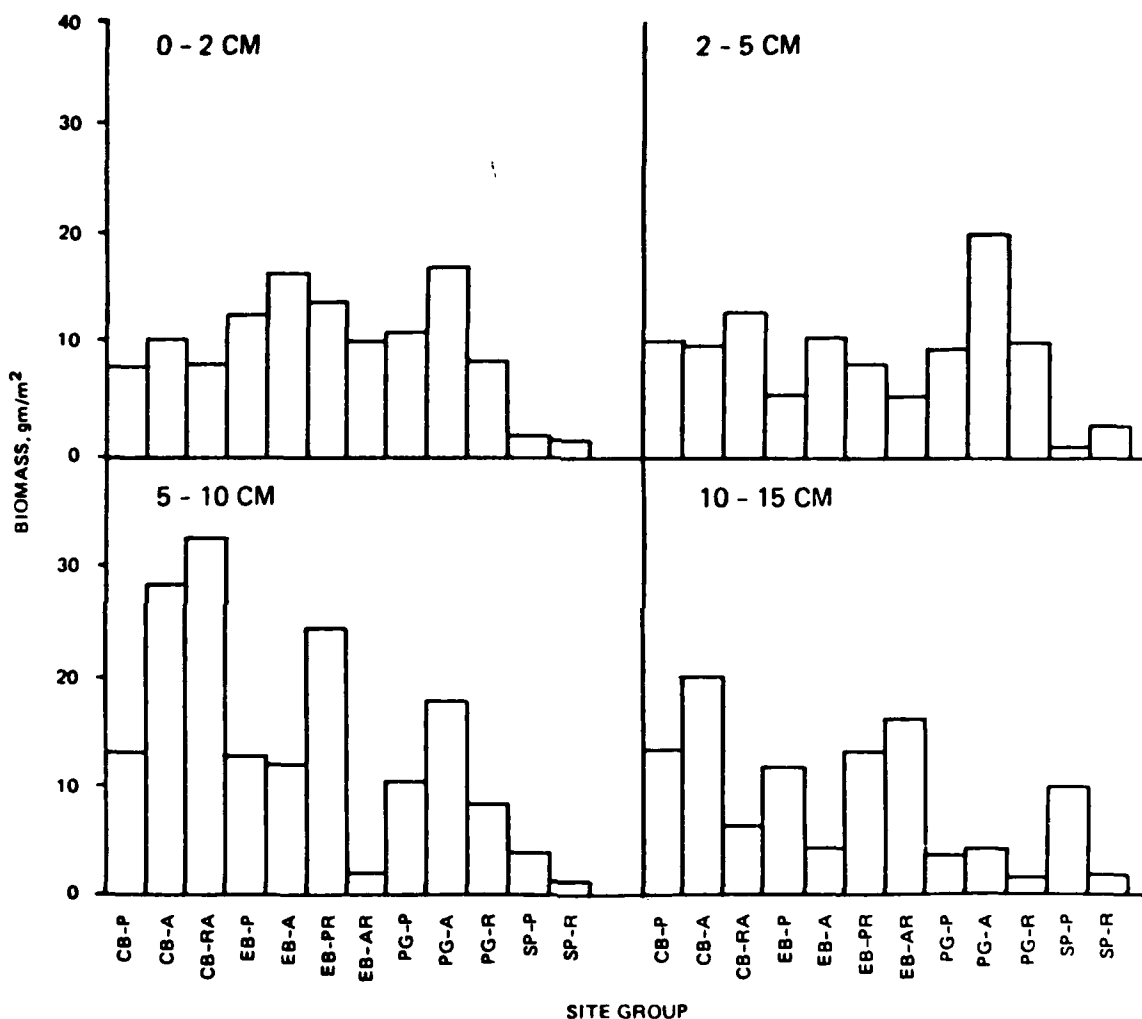
Figure 8. Vertical distribution of benthic biomass for the 0-2, 0-5, 0-10, and 0-15 cm sediment depth fractions among the Puget Sound study areas. CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage, P = Primary Site, A = Alternative Site, RA = Reference Area, PR = Primary Reference, AR = Alternative Reference.

32
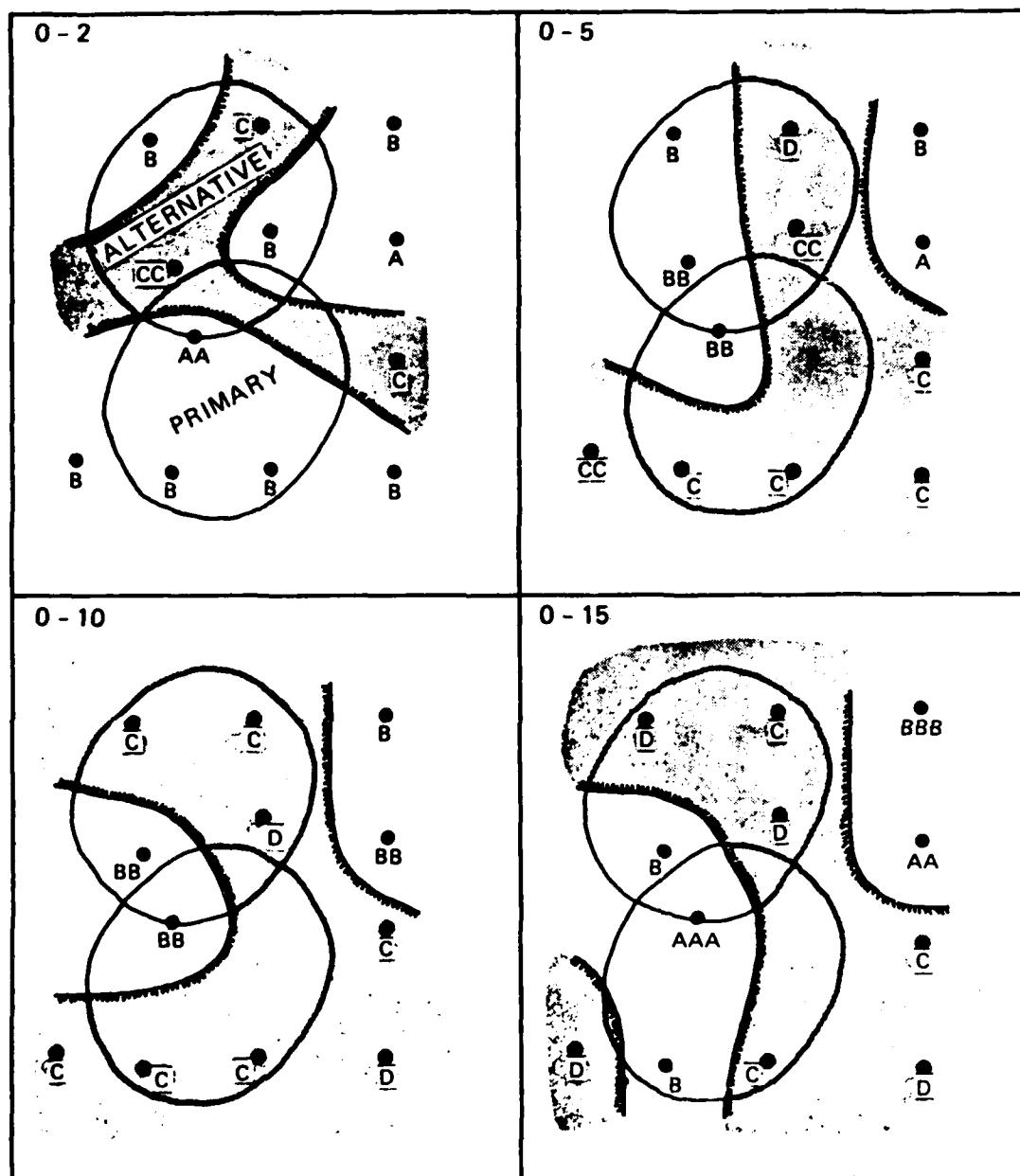
Figure 9. Benthic biomass strata at the Commencement Bay study area. Strata A, AA, B, BB, and BBB are indicative of low biomass concentrations, whereas Strata C, CC, and D are indicative of high biomass concentrations.
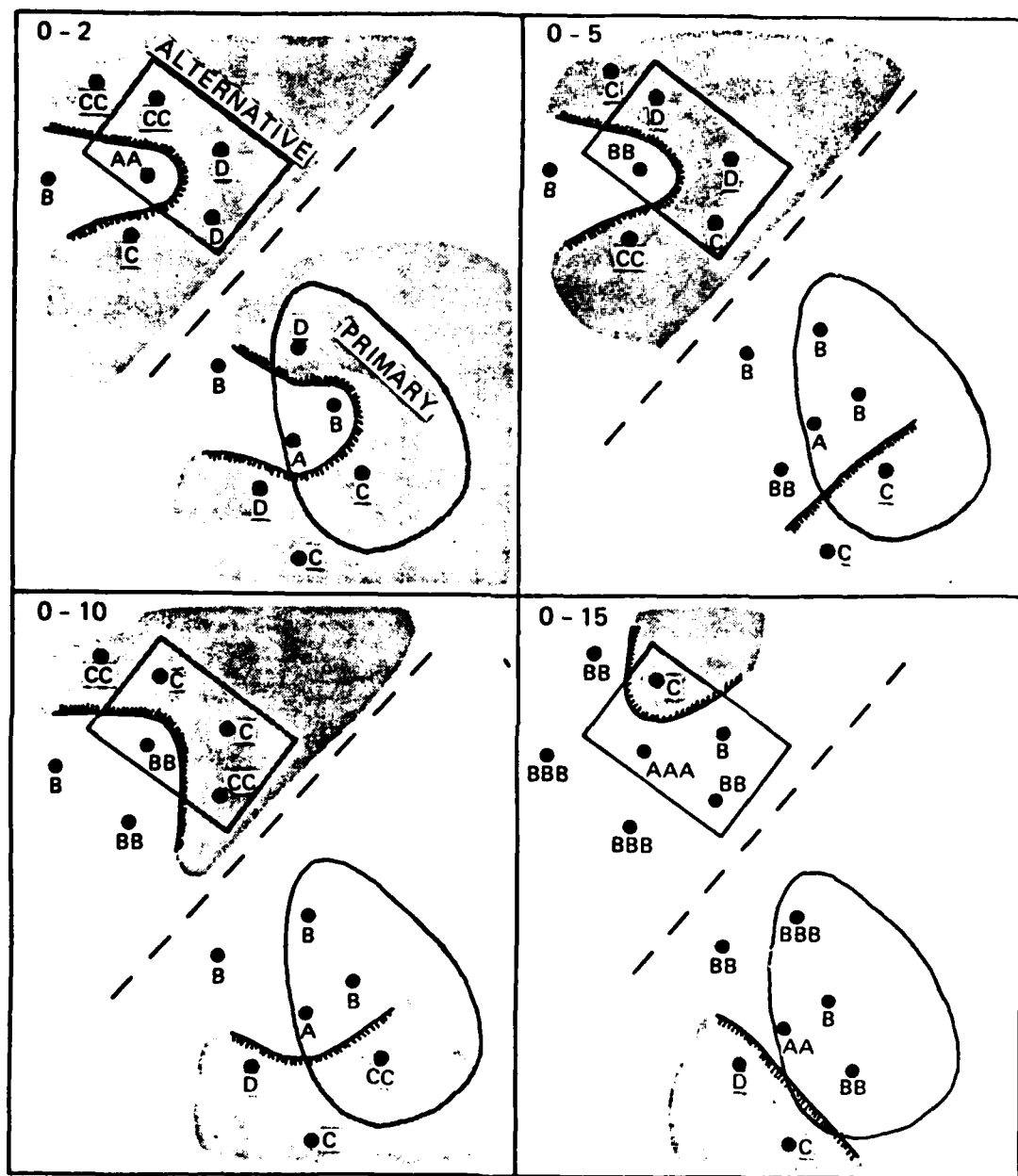
Figure 10. Benthic biomass strata at the Elliott Bay study area. Strata A, AA, AAA, B, and BB are indicative of low biomass concentrations, whereas strata C, CC, and D are indicative of high biomass concentrations.
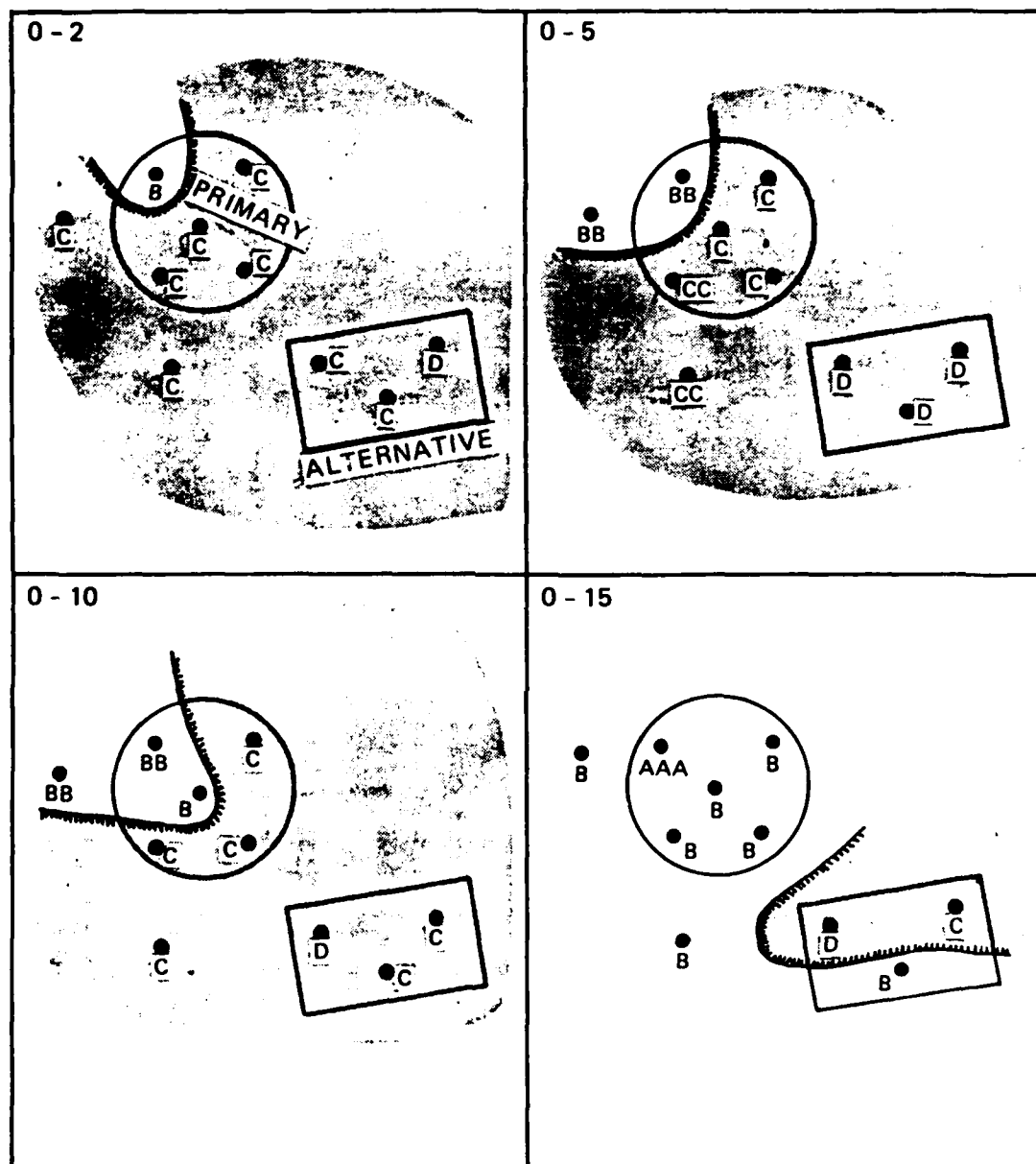
Figure 11.   Benthic biomass strata at the Port Gardner study area.
Strata A, AA, AAA, B, and BB are indicative of low
biomass concentrations, whereas strata C, CC, and D are
indicative of high biomass concentrations.
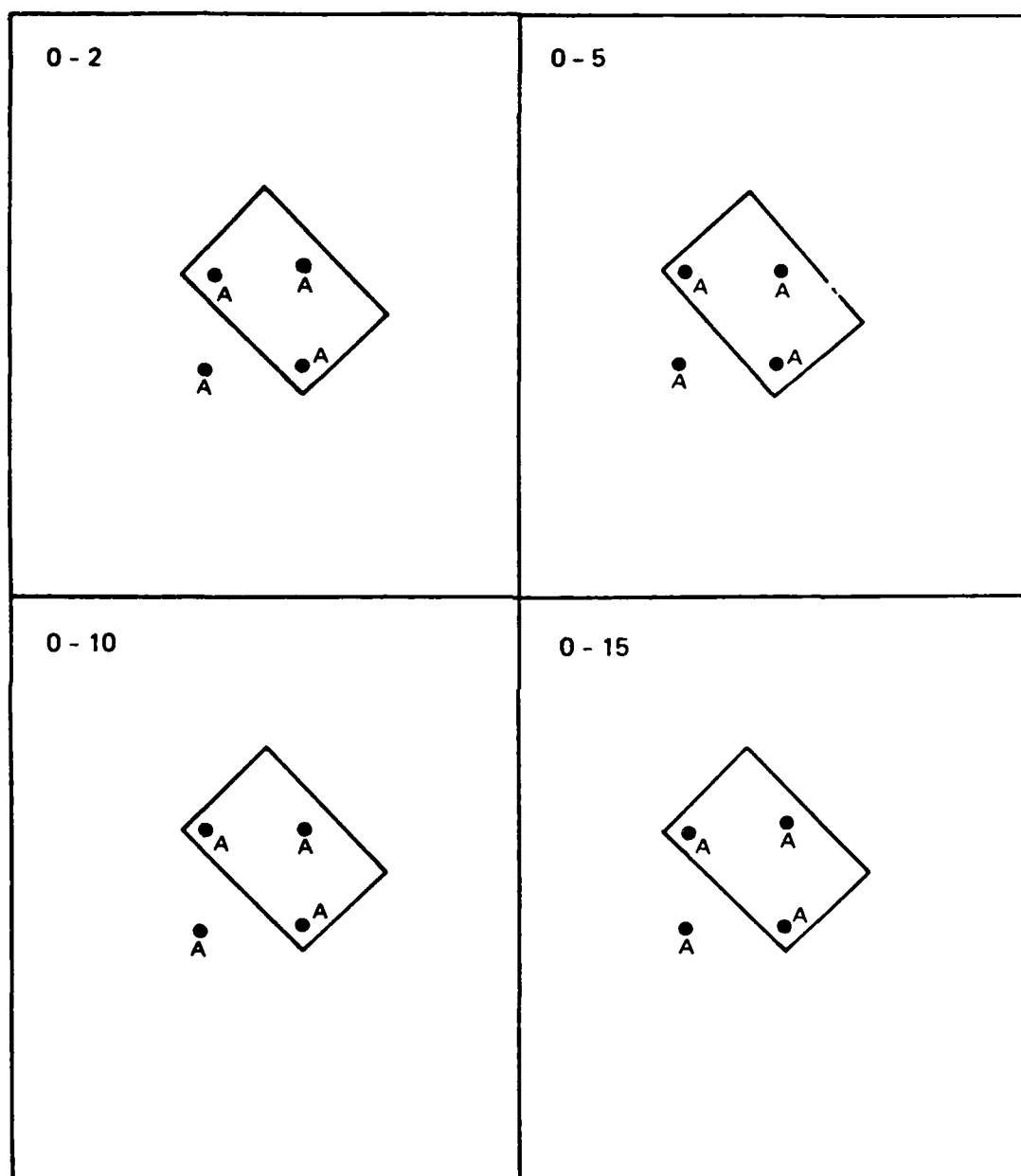
Figure 12. Benthic biomass strata at the Saratoga Passage study
area. All stations fall in Stratum A, which is
indicative of low biomass concentrations.
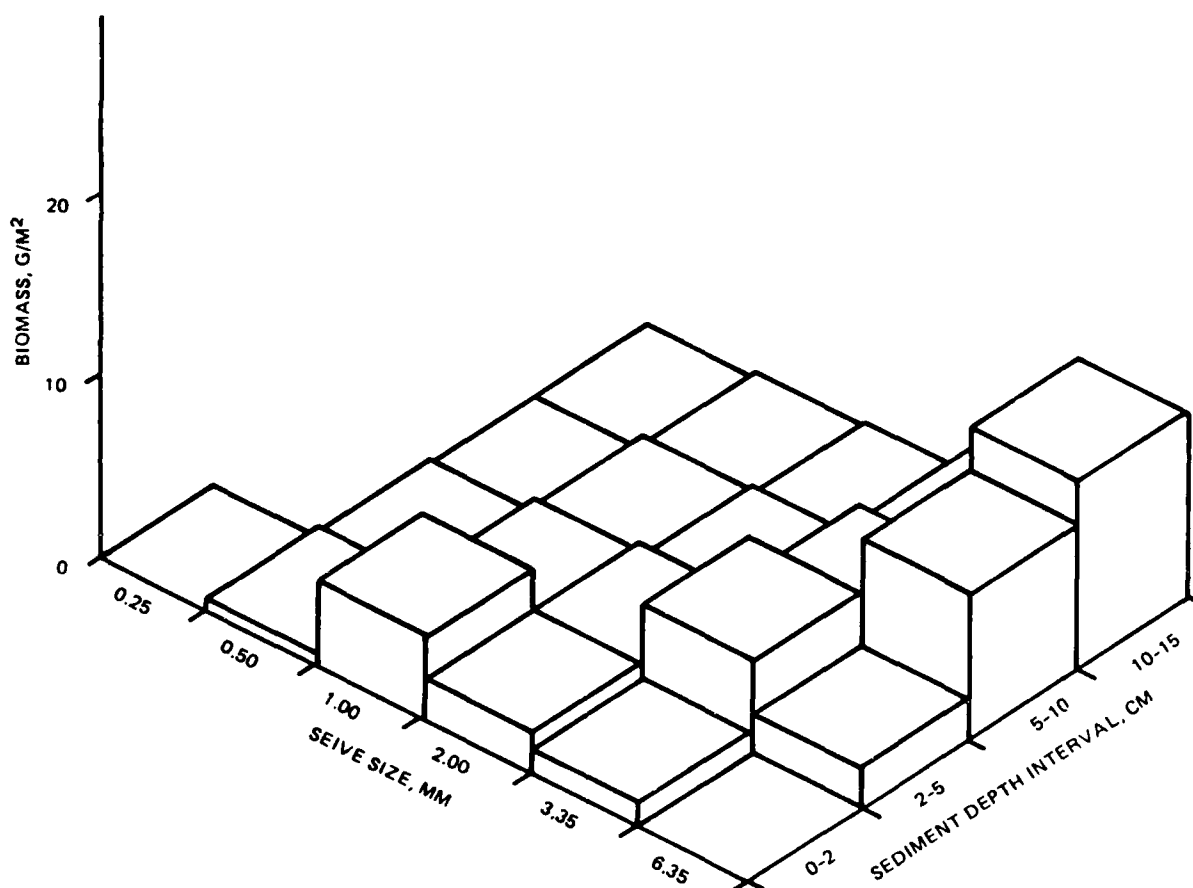
Figure 13. Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the Primary
Disposal Site at the Commencement Bay study area.
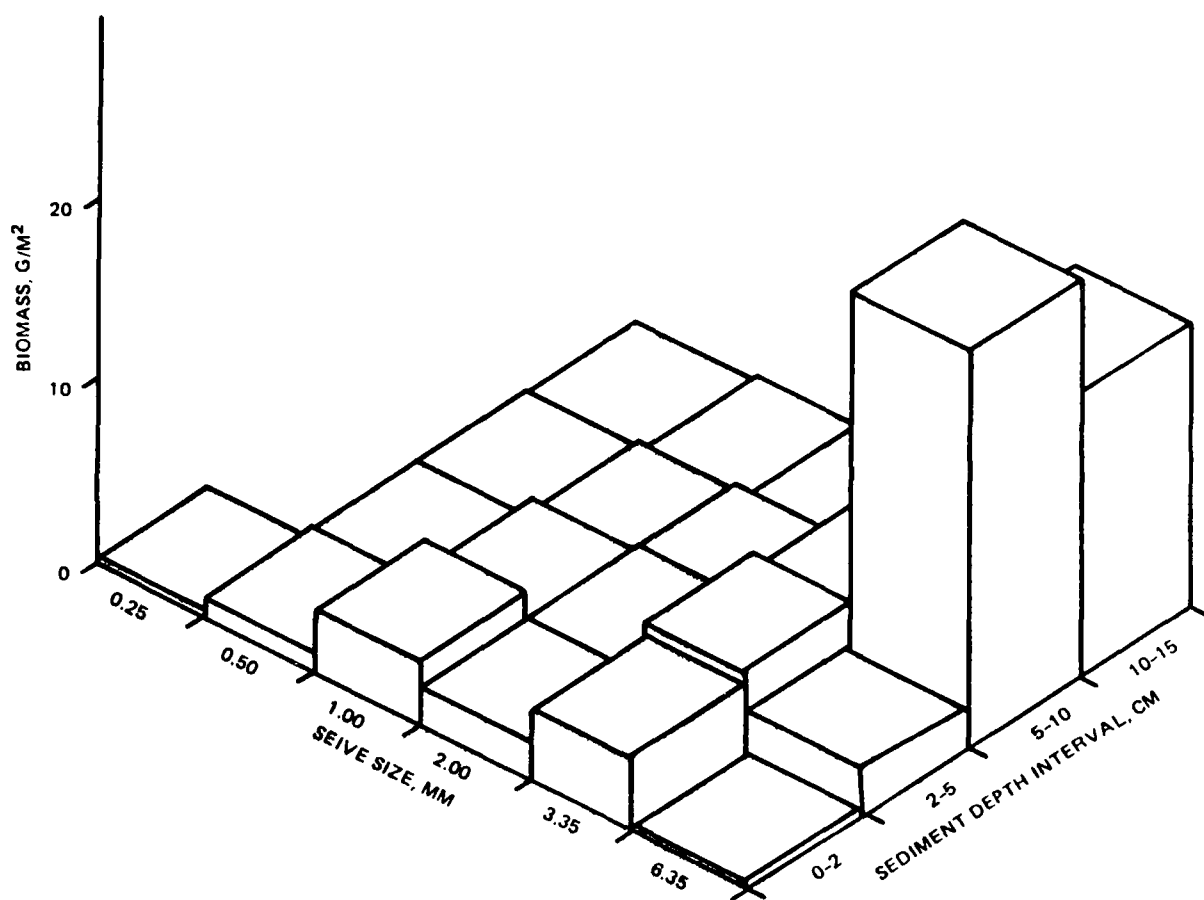
Figure 14. Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the
Alternative Disposal Site at the Commencement Bay study
area.
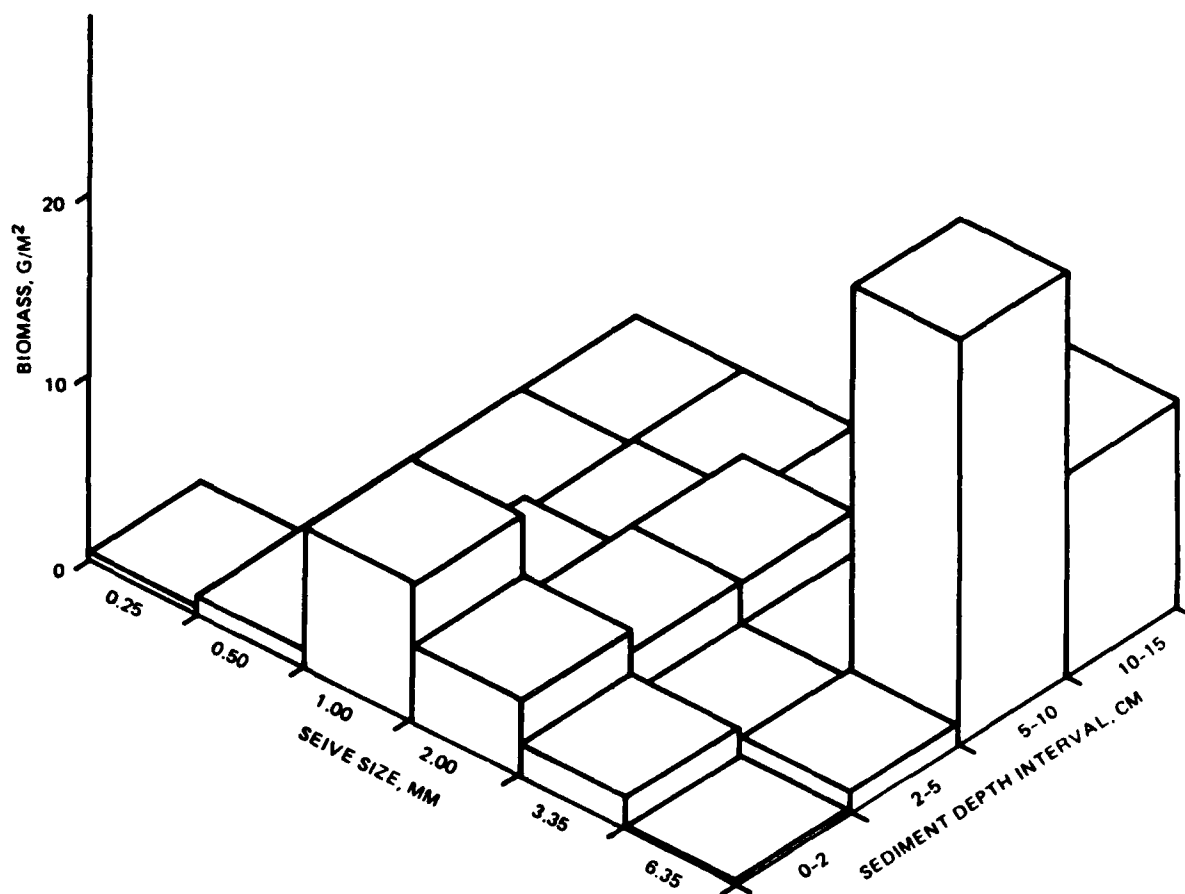
Figure 15. Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the
Reference Sites at the Commencement Bay study area.
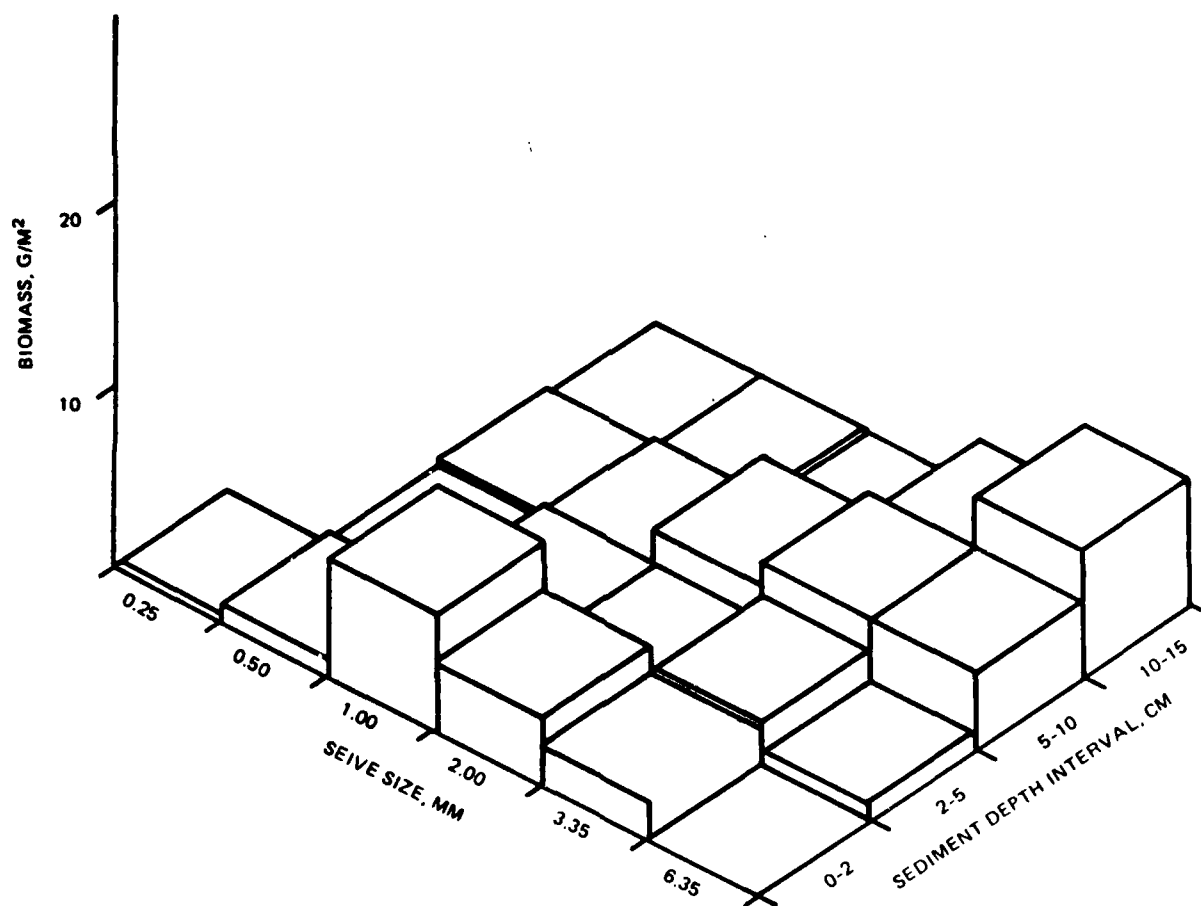
Figure 16. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Primary Disposal Site at the Elliott Bay study area.
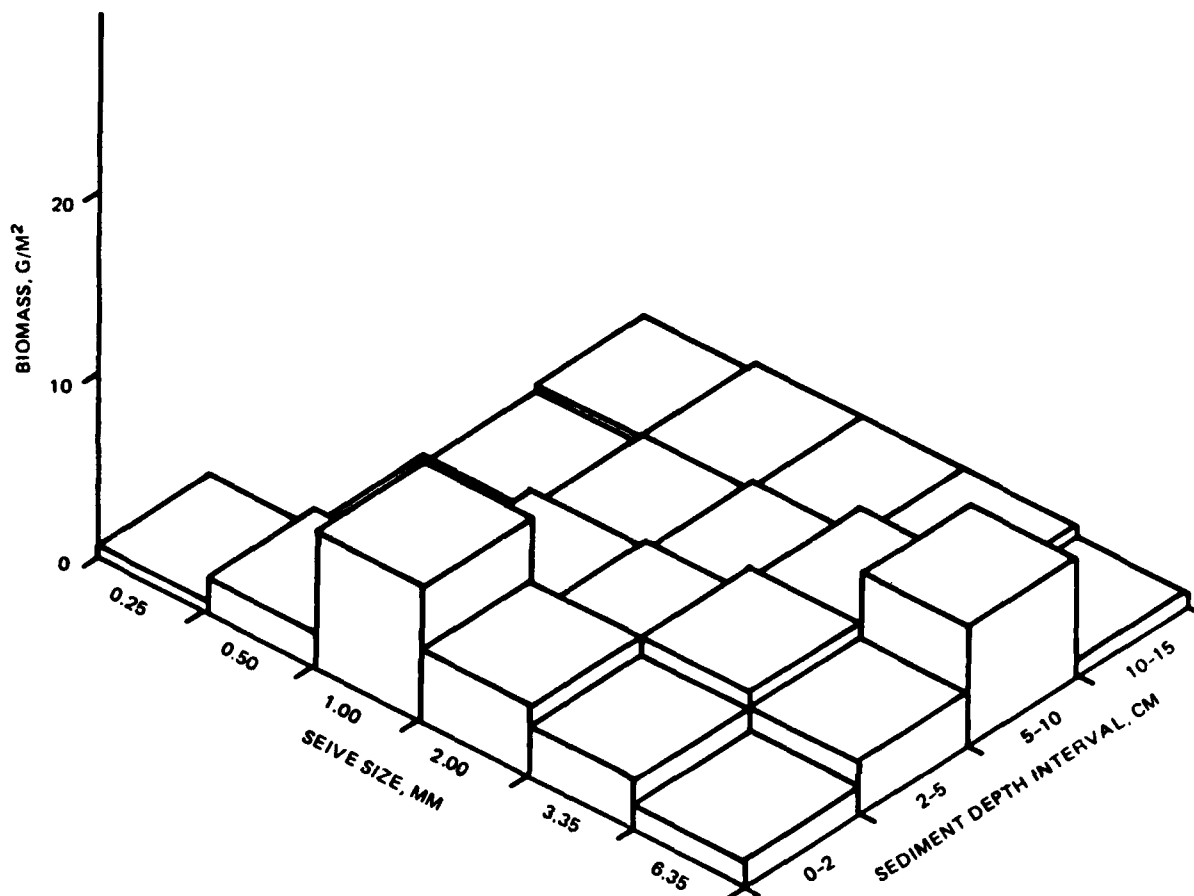
Figure 17. Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the
Alternative Disposal Site at the Elliott Bay study area.
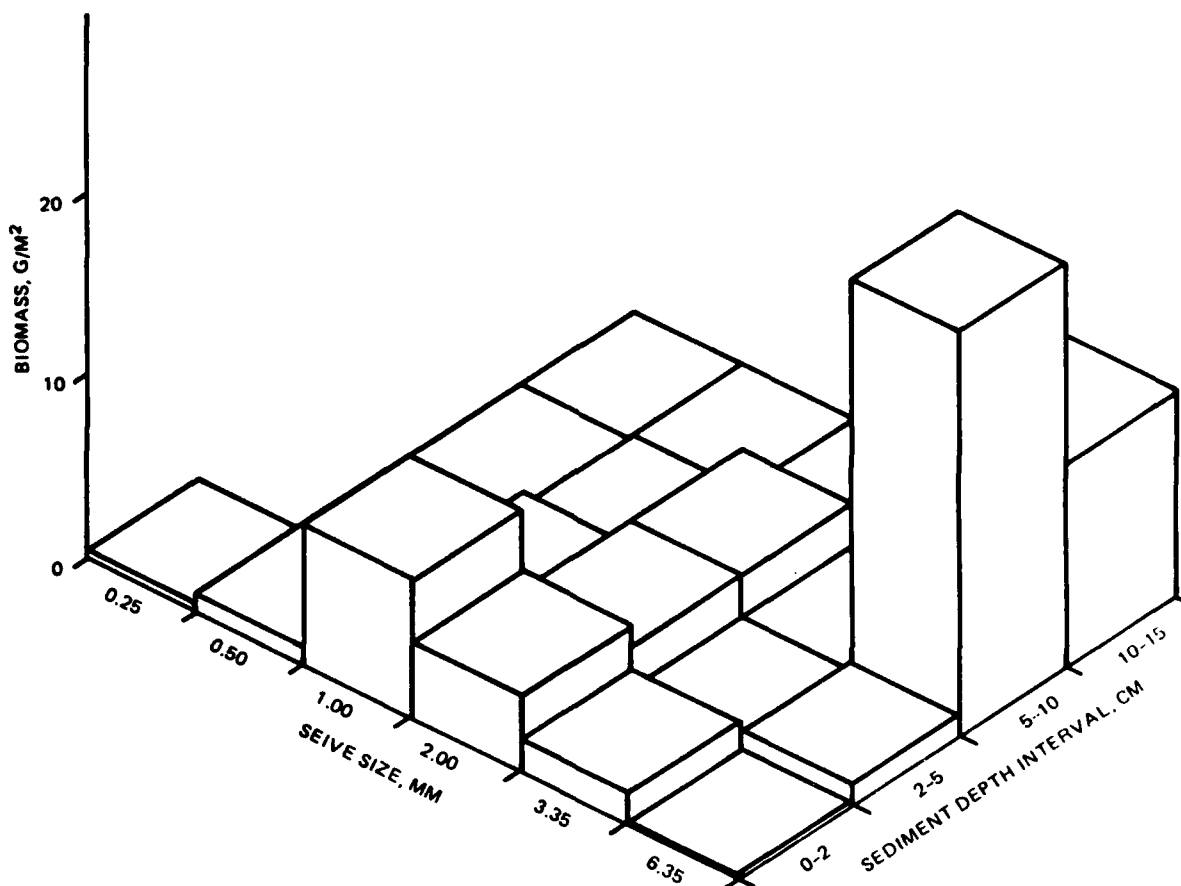
Figure 18. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Primary Reference Site at the Elliott Bay study area.

42
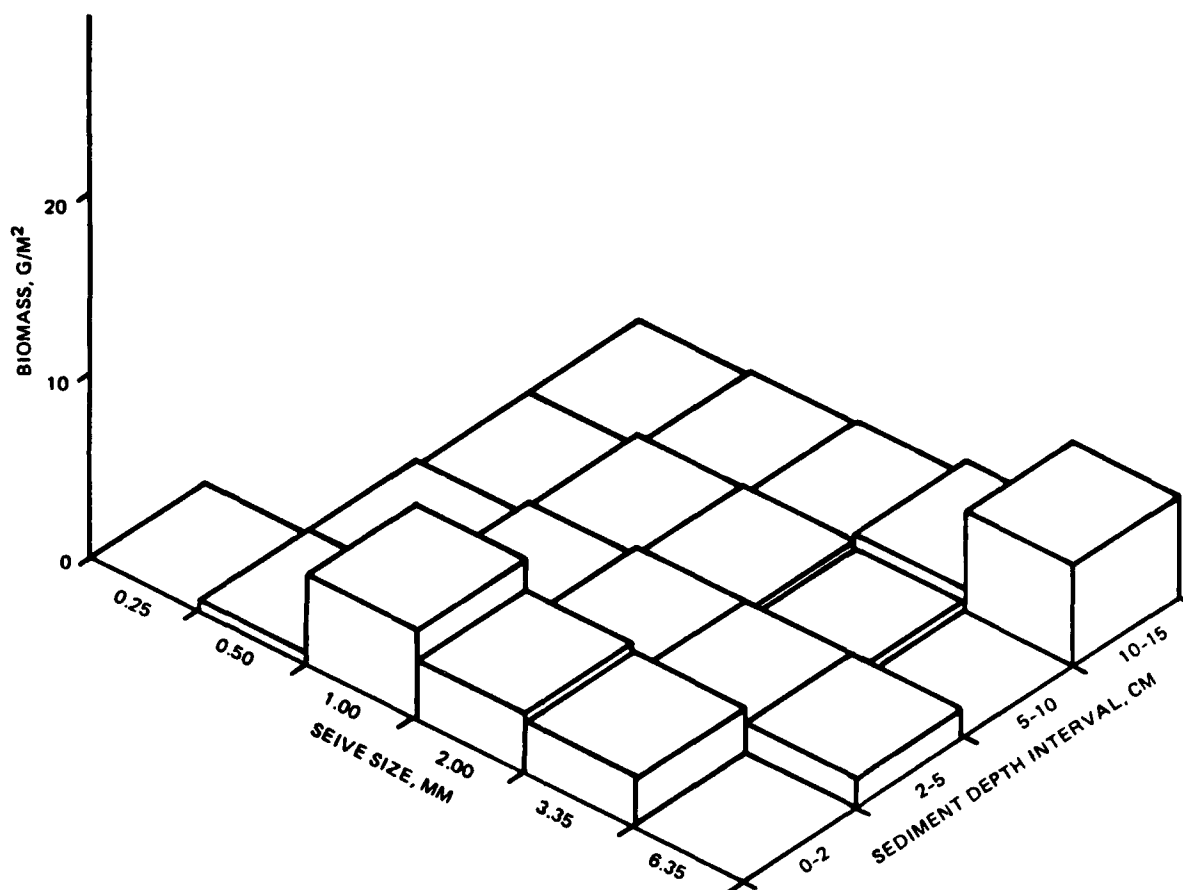
Figure 19.   Three dimensional plot of benthic biomass across size
             categories and sediment depth intervals for the
             Alternative Reference Site at the Elliott Bay study area.
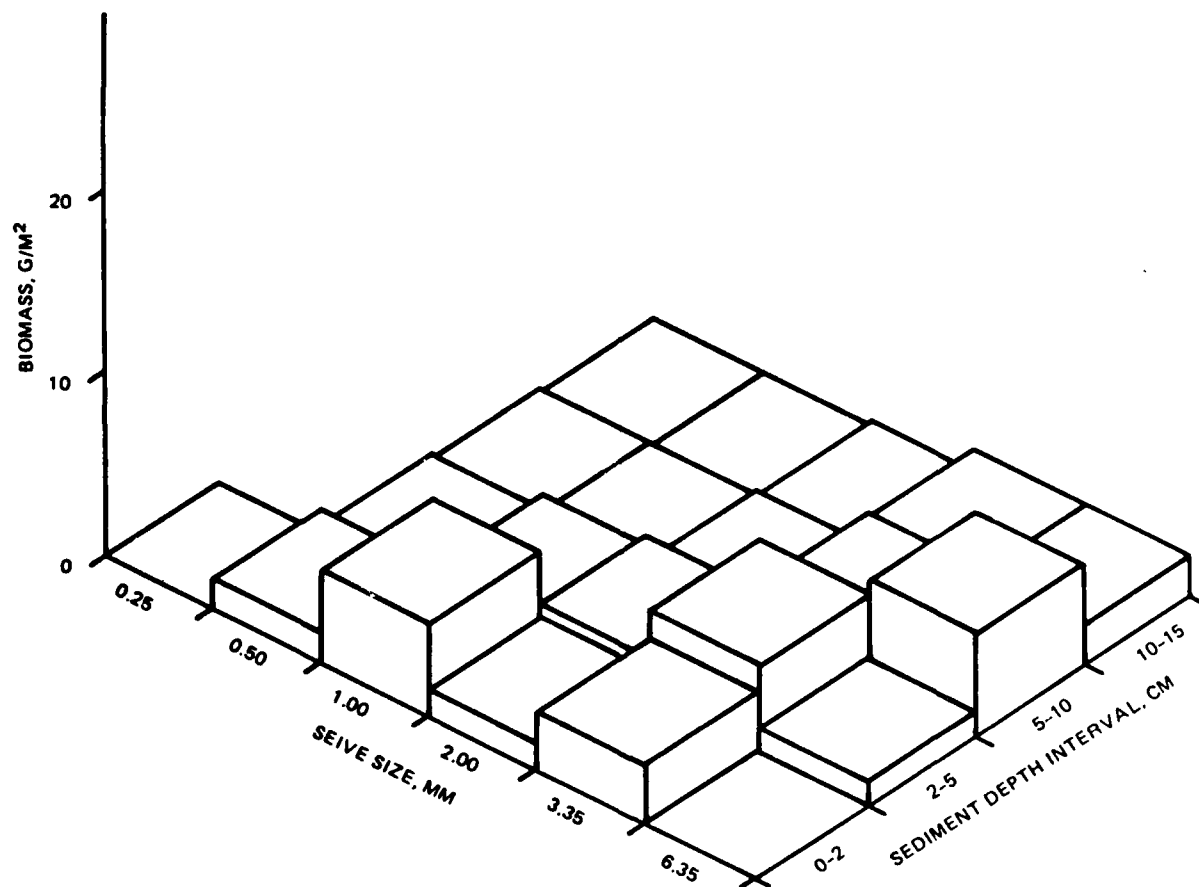
Figure 20. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Primary Disposal Site at the Port Gardner study area.

44
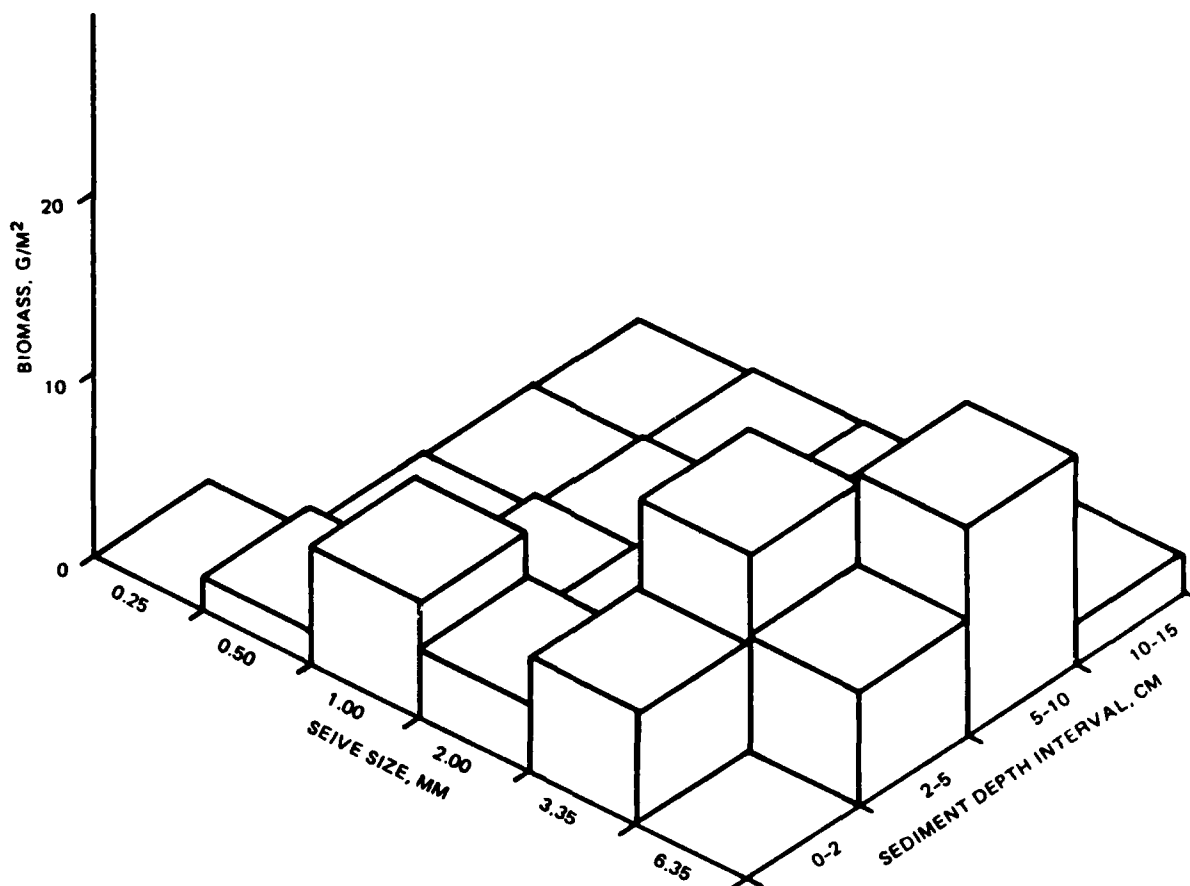
Figure 21.   Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the
Alternative Disposal Site at the Port Gardner study
area.
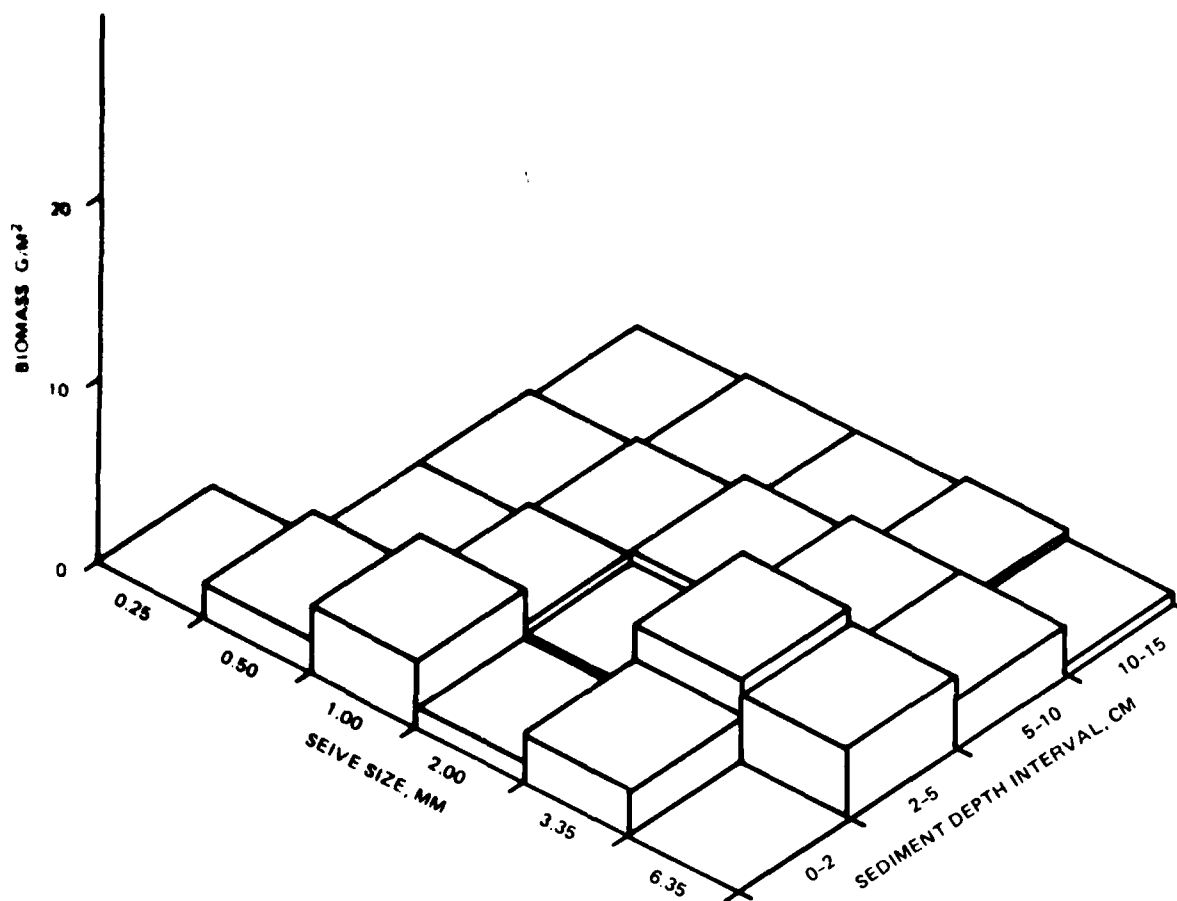
Figure 22.   Three dimensional plot of benthic biomass across size
categories and sediment depth intervals for the
Reference Sites at the Port Gardner study area.

Figure 23. Taxonomic composition of the diets of fishes sampled
            in the Puget Sound study areas. LE = slender sole,
            MP = Dover sole, HE = flathead sole, PV = English
            sole, GZ = rex sole, CB = Commencement Bay, EB =
            Elliott Bay, PG = Port Gardner, SP = Saratoga
            Passage. Numeral following species code indicates
            size class (cm SL). 1 = 5-9.9. 2 = 10-14.9, 3 = 15-
            19.9, 4 = 20-24.9, 5 = 25-29.9, 6 = 30-34.9. See
            text for trawl location designations.
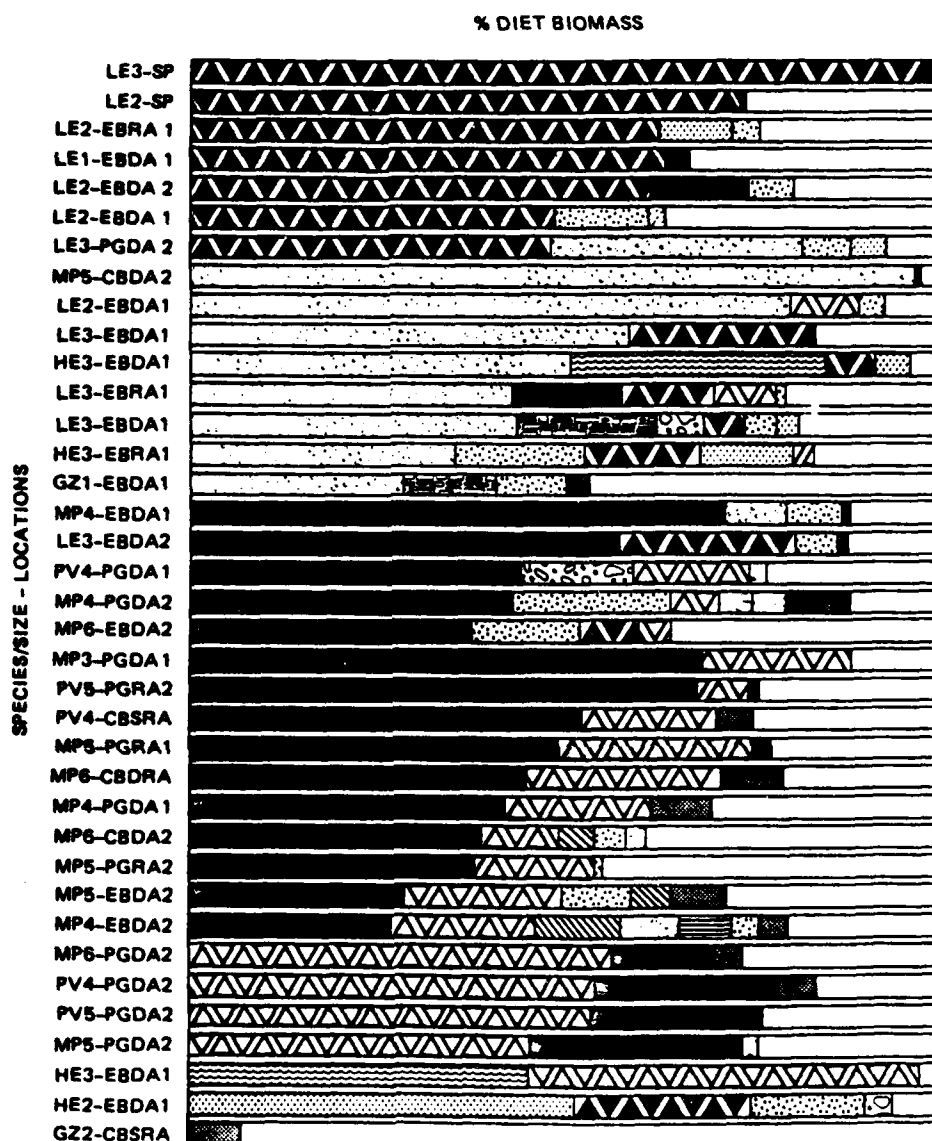
% DIET BIOMASS

SPECIES/SIZE - LOCATIONS

LE3-SP
LE2-SP
LE2-EBRA 1
LE1-EBDA 1
LE2-EBDA 2
LE2-EBDA 1
LE3-PGDA 2
MP5-CBDA2
LE2-EBDA1
LE3-EBDA1
HE3-EBDA1
LE3-EBRA1
LE3-EBDA1
HE3-EBRA1
GZ1-EBDA1
MP4-EBDA1
LE3-EBDA2
PV4-PGDA1
MP4-PGDA2
MP6-EBDA2
MP3-PGDA1
PV5-PGRA2
PV4-CBSRA
MP6-PGRA1
MP6-CBDRA
MP4-PGDA1
MP6-CBDA2
MP5-PGRA2
MP5-EBDA2
MP4-EBDA2
MP6-PGDA2
PV4-PGDA2
PV5-PGDA2
MP5-PGDA2
HE3-EBDA1
HE2-EBDA1
GZ2-CBSRA

LEGEND

- MYSIDACEA
- DECAPODA
- POLYCHAETA
- BIVALVIA
- FISH
- NEMATODA
- CRUSTACEA
- AMPHIPODA
- UNIDENTIFIED
- HOLOTHUROIDEA
- OPHIUROIDEA
- UROCHORDATA
- OSTRACODA
- MISCELLANEOUS
- ISOPODA
- CUMACEA
- COPEPODA

48
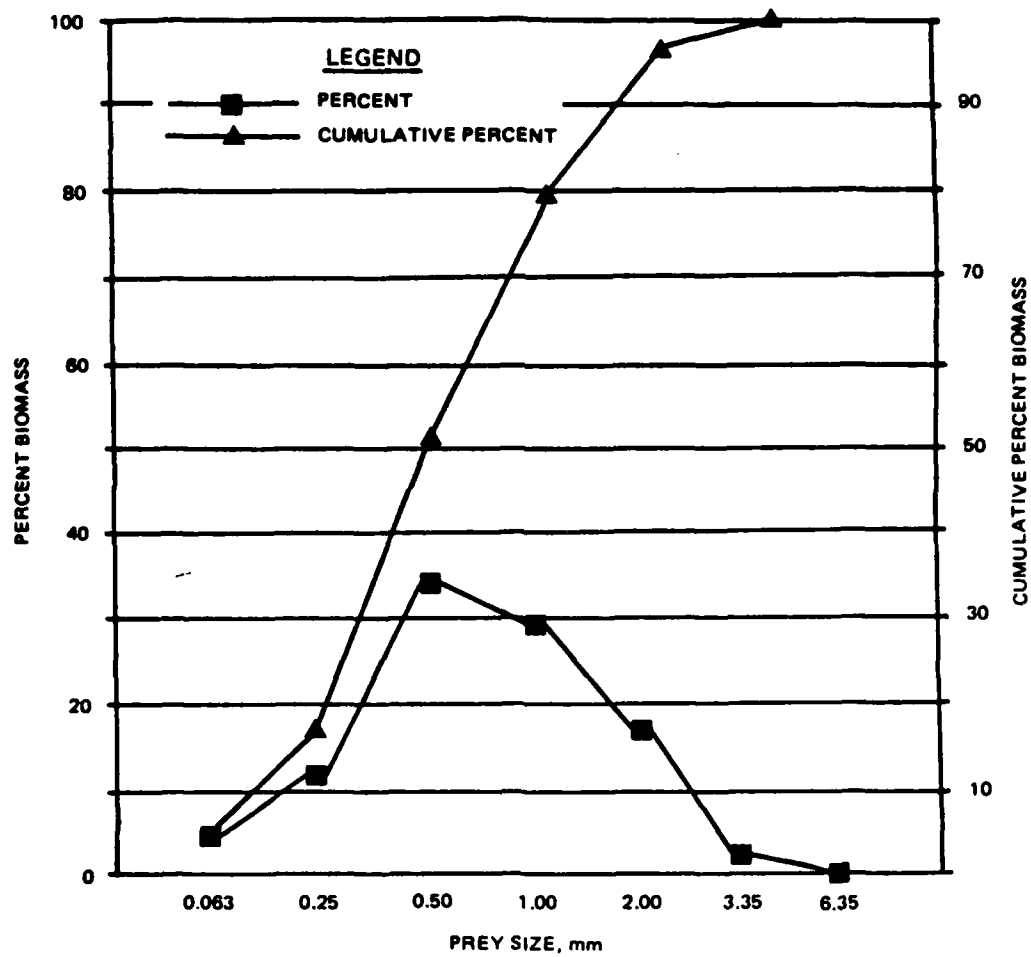
Figure 24.   Prey size exploitation pattern for predators in
              Group IIA.
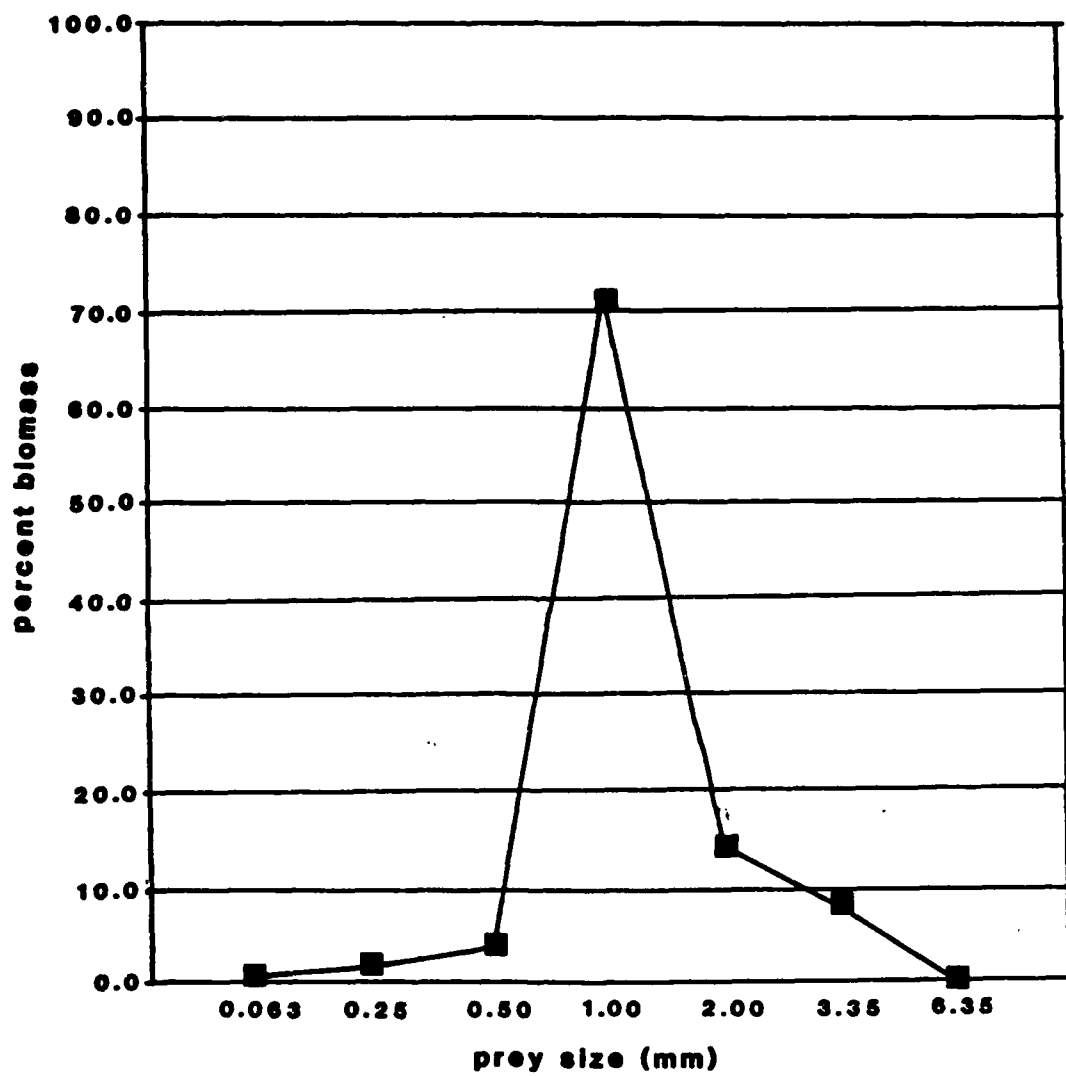
Figure 25.   Prey size exploitation pattern for predators in
             Group II.

50
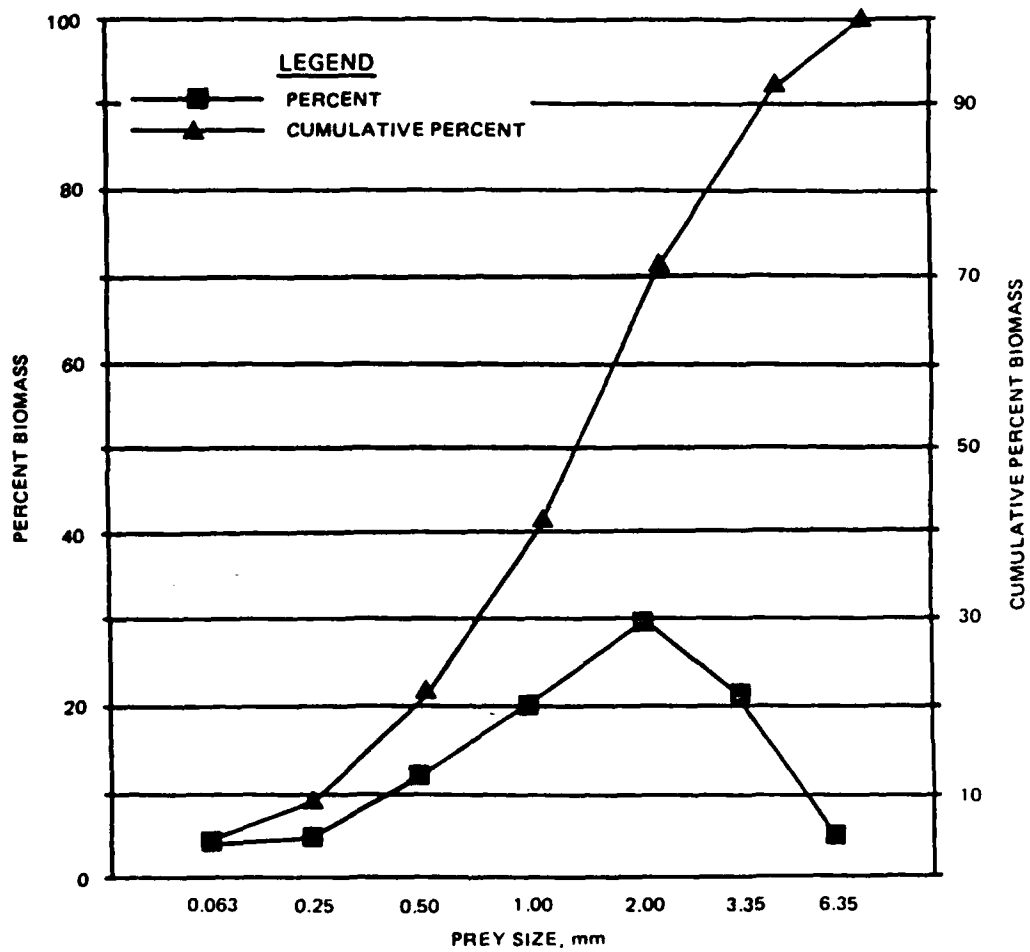
Figure 26. Prey size exploitation pattern for predators in Group IIB.

51
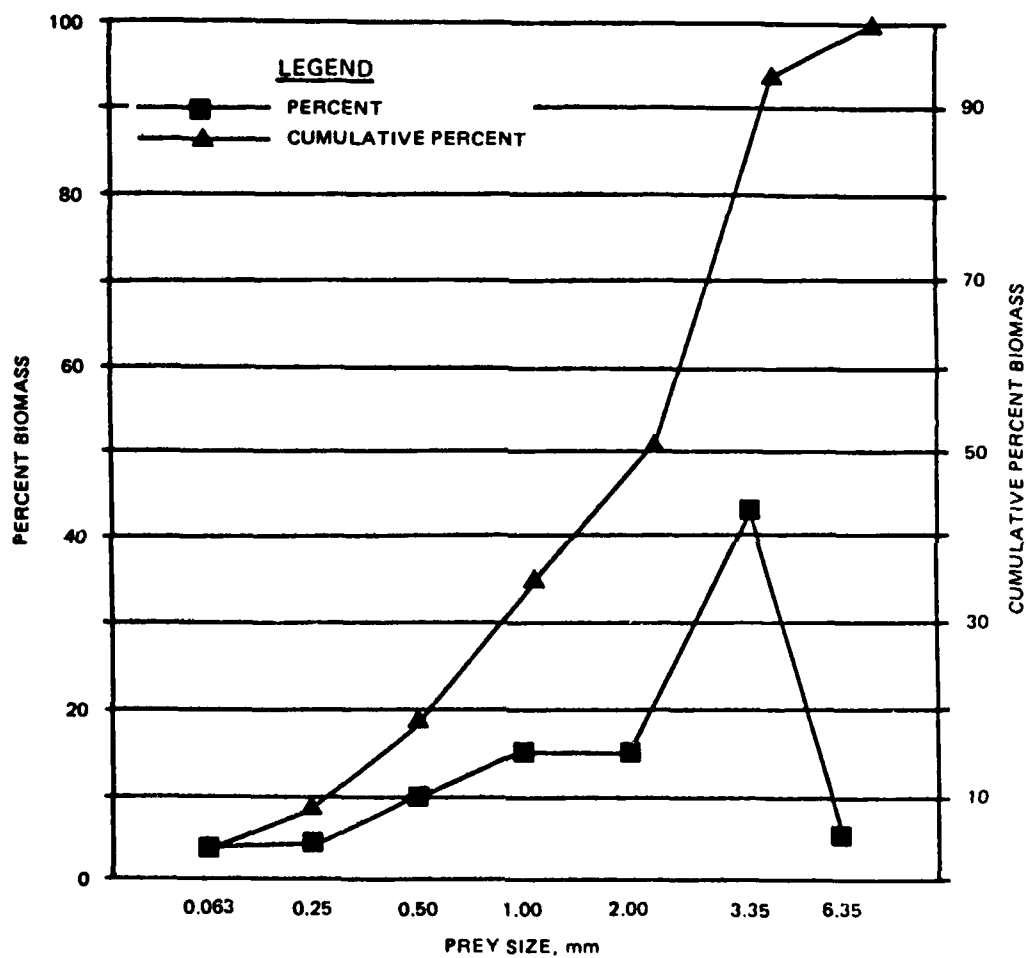
Figure 27. Prey size exploitation pattern for predators in
Group IIC.
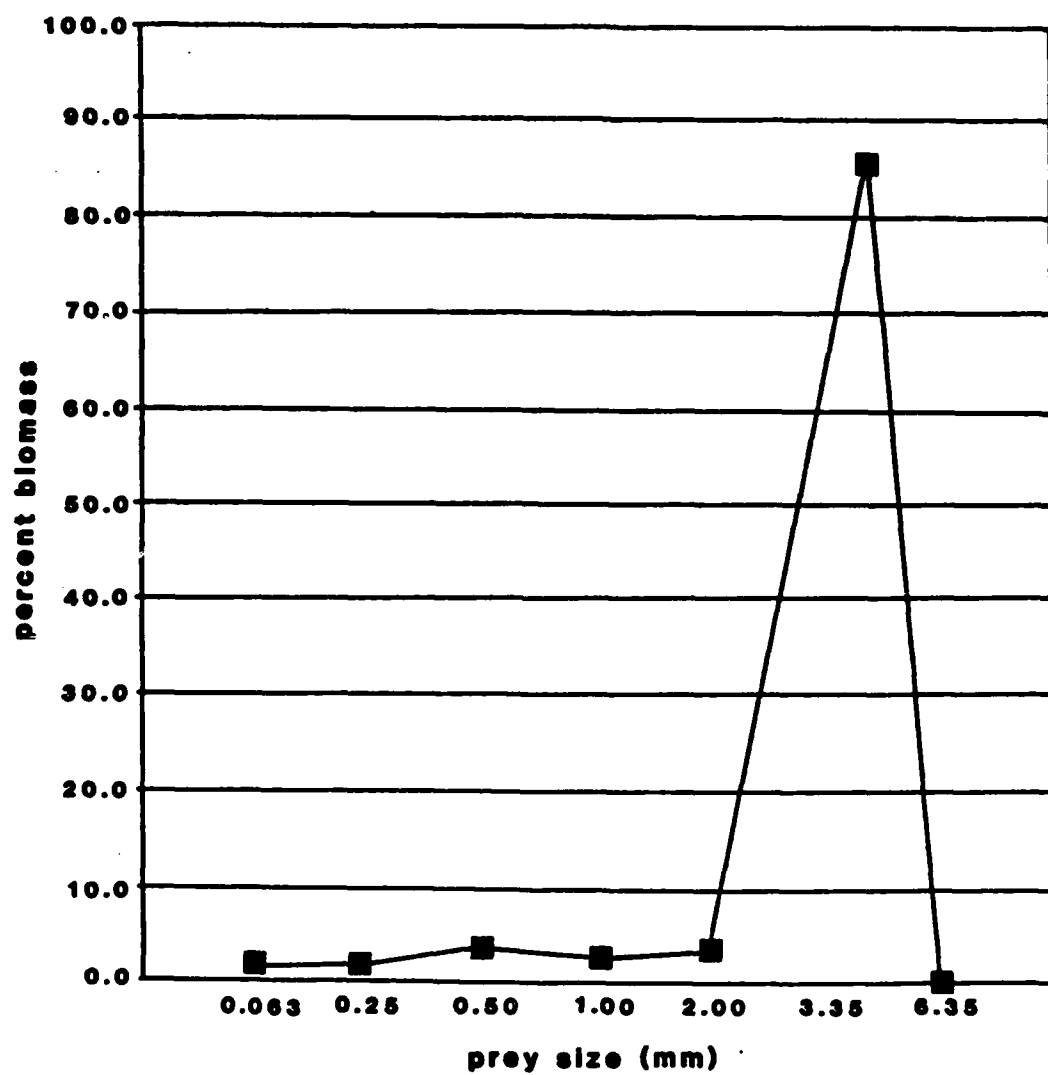
Figure 28.   Prey size exploitation pattern for predators in
Group IID.

53
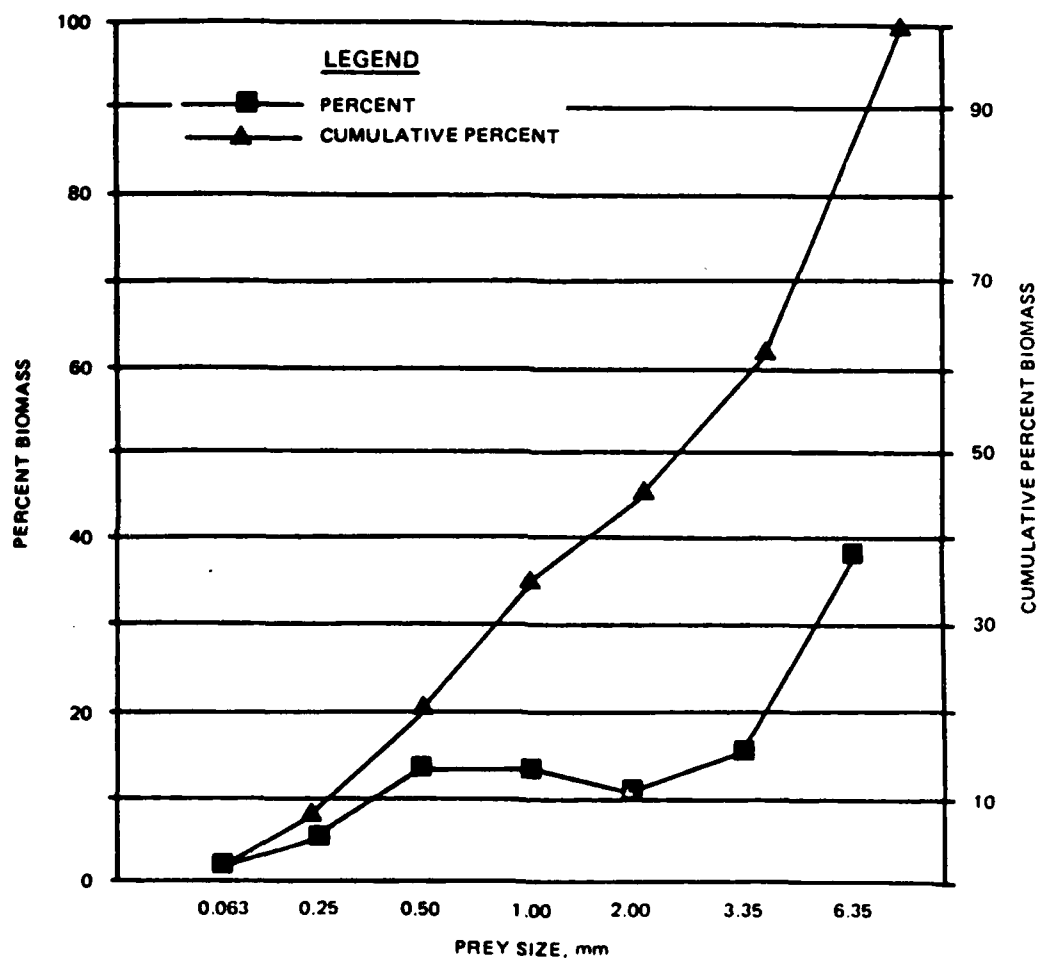
Figure 29. Prey size exploitation pattern for predators in Group IIIA.

54
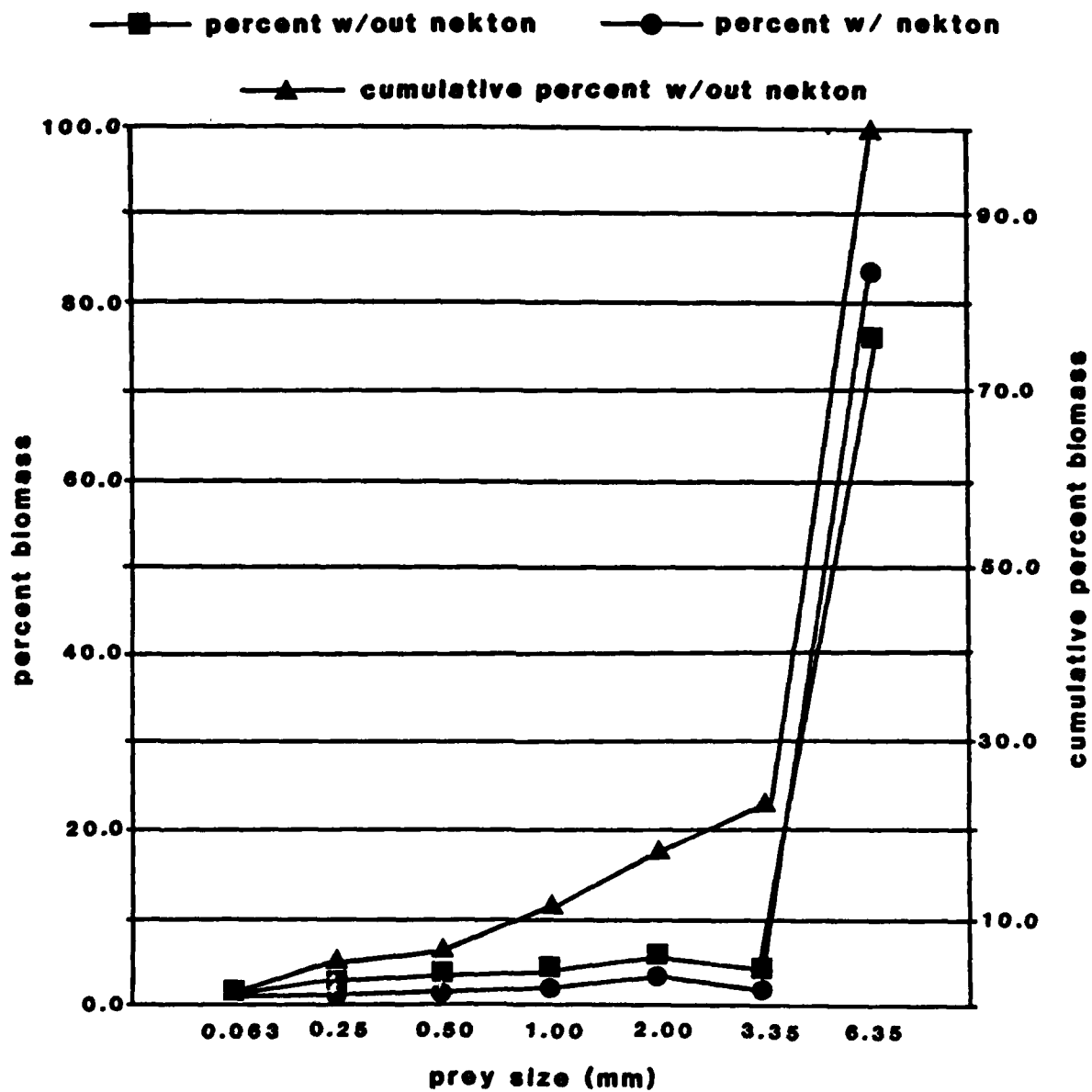
Figure 30. Prey size exploitation pattern for predators in
Group IIIB.

Figure 31. Size distribution of benthic biomass among benthic
strata in the 0-5 cm sediment depth interval for
the Puget Sound study areas.

BENTHIC STRATUM

A   C
B   CC
BB D

SIZE, MM

BENTHIC BIOMASS, G/M²

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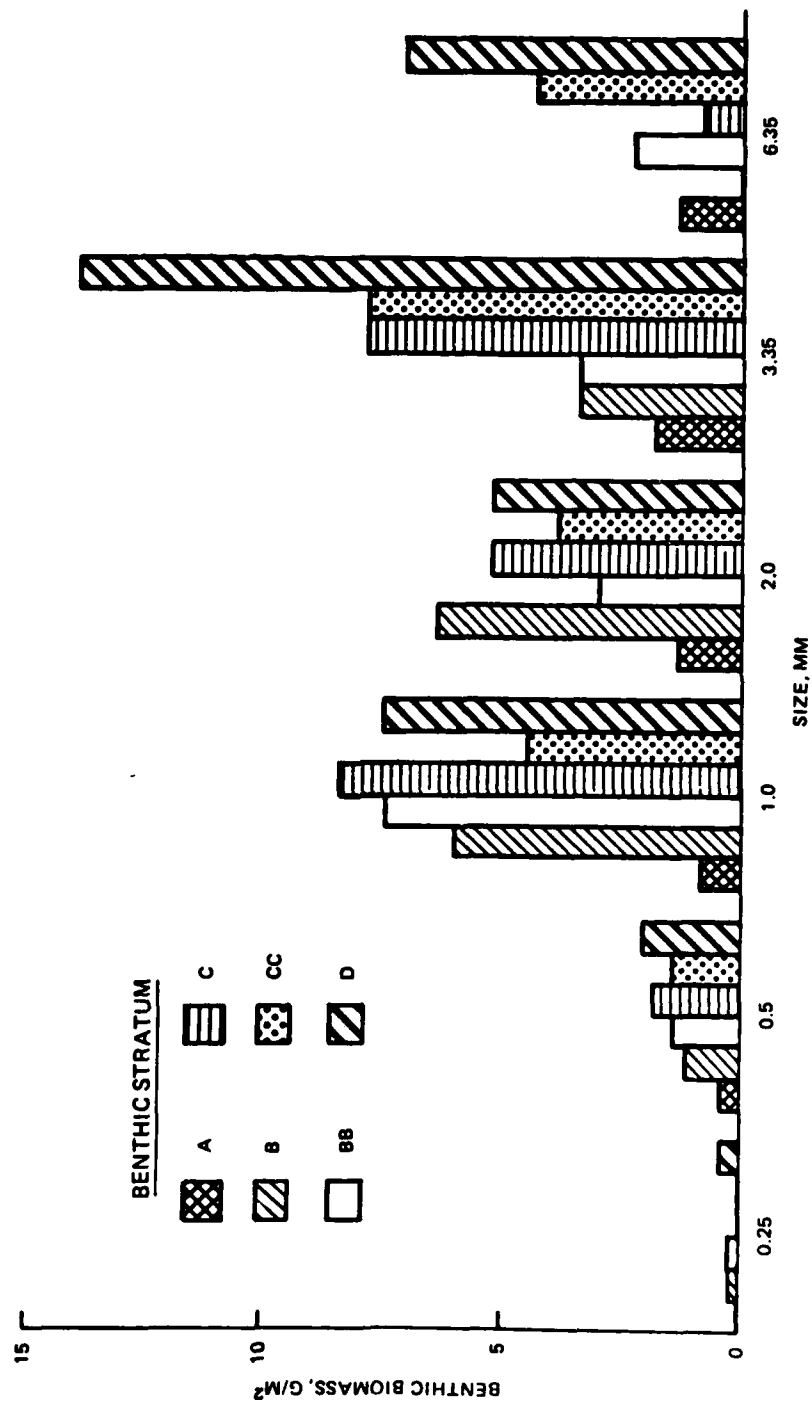
Figure 32. Size distribution of benthic biomass among benthic
strata in the 0-10 cm sediment depth interval for the
Puget Sound study areas.

BENTHIC STRATUM

A
B
BB
C
CC
D

BENTHIC BIOMASS

0   5   10   15   19

SIZE, MM

0.25   0.50   1.00   2.00   3.35   6.35

Figure 33. Distribution of potential trophic resource value among benthic biomass strata for various predator feeding groups in the Puget Sound study areas.

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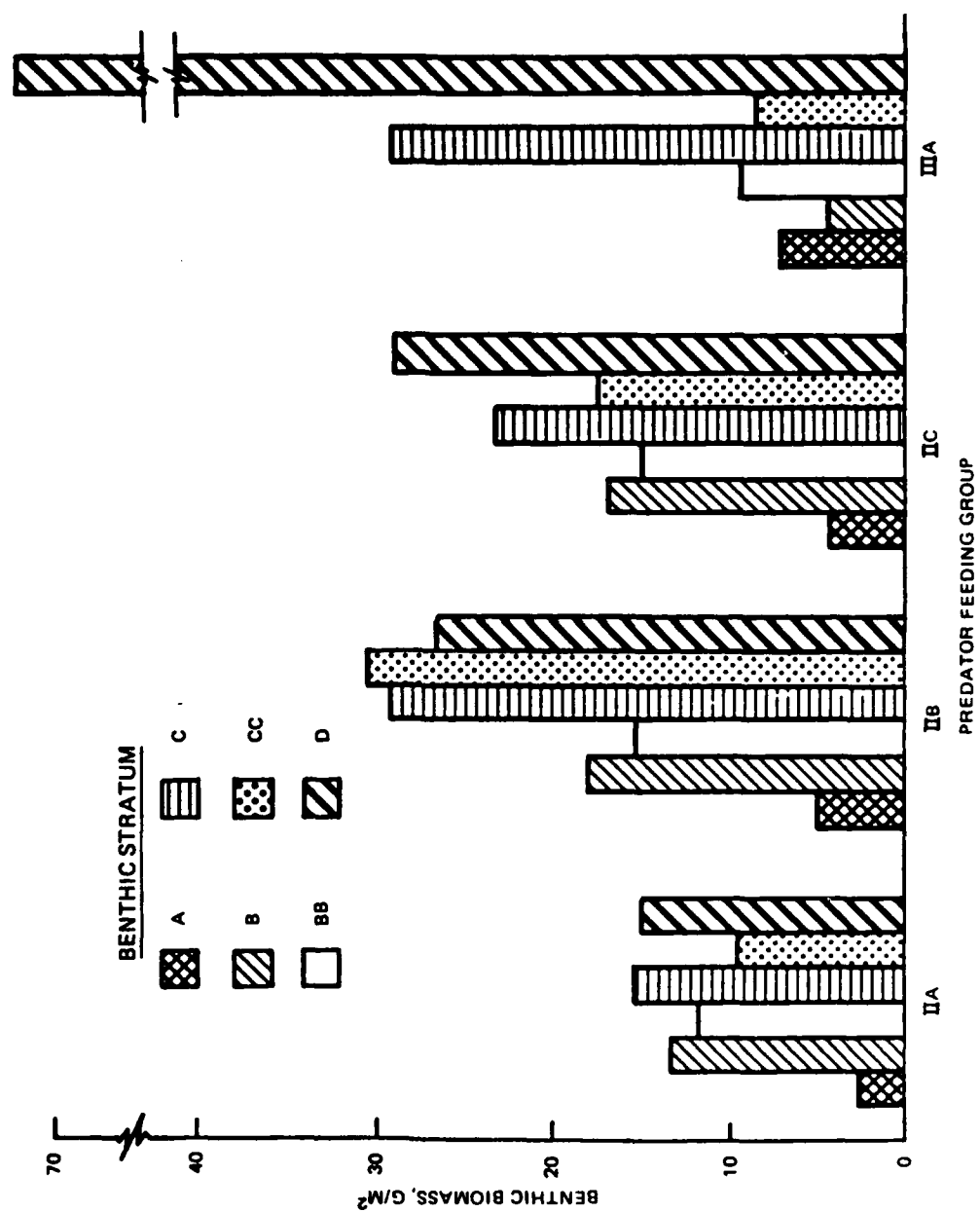
Table 1. Size distribution of total benthic biomass (pooled across all vertical sediment depthy fractions) among study areas. Table values are in g/sq m. CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage, P = Primary Disposal Site, A = Alternative Disposal Site, R = Refence Site, PR = Primary Refernce Site, AR = Alternative Reference Site

| | | Biomass Size Category (mm) |
		0.25	0.50	1.00	2.00	3.35	6.35	Total
Mollusca	CB-P	0.002	0.056	4.513	2.755	2.962	2.550	12.837
	CB-A	0.028	0.035	2.350	3.923	3.282	2.202	11.820
	CB-R	0.008	0.132	3.741	4.465	3.392	3.750	15.488
	EB-P	0.020	0.581	6.665	4.015	2.633	2.250	16.163
	EB-A	0.307	0.930	8.575	6.292	5.142	4.884	26.129
	EB-PR	0.004	0.278	8.028	4.322	2.235	0.000	14.868
	EB-AR	0.013	0.084	5.210	3.724	1.680	9.585	20.295
	PG-P	0.007	0.908	4.904	2.324	6.363	0.000	14.506
	PG-A	0.026	0.614	4.927	2.901	17.792	3.760	30.019
	PG-R	0.014	0.722	3.282	0.785	3.956	1.294	10.054
	SP-P	0.017	0.044	0.145	0.465	0.309	0.000	0.979
	SP-R	0.000	0.045	0.152	0.430	0.082	0.000	0.709
Annelida	CB-P	0.008	0.522	0.984	2.458	8.633	18.096	30.700
	CB-A	0.014	0.537	1.236	1.588	9.566	37.445	50.386
	CB-R	0.005	0.731	1.096	2.649	7.326	12.102	23.908
	EB-P	0.039	1.317	1.689	3.838	6.450	8.015	21.348
	EB-A	0.150	0.879	1.398	2.315	4.493	6.723	15.958
	EB-PR	0.258	1.560	1.836	2.976	1.390	33.237	41.256
	EB-AR	0.006	0.365	0.479	1.086	3.893	7.034	12.863
	PG-P	0.029	1.206	1.597	1.829	5.284	7.273	17.219
	PG-A	0.070	1.523	2.886	2.765	5.282	5.347	17.873
	PG-R	0.042	1.462	2.274	2.359	5.840	4.013	15.991
	SP-P	0.014	0.148	0.482	0.577	0.479	0.430	2.130
	SP-R	0.000	0.197	0.598	0.382	1.621	3.405	6.203
Crustacea	CB-P	0.020	0.538	1.172	0.324	0.268	0.000	2.322
	CB-A	0.052	1.140	2.027	0.373	0.035	0.821	4.447
	CB-R	0.017	0.606	1.107	0.303	0.885	0.544	3.462
	EB-P	0.016	0.193	0.250	0.077	2.300	1.324	4.159
	EB-A	0.032	0.902	0.900	0.241	0.999	0.000	3.074
	EB-PR	0.010	0.206	0.158	3.279	0.054	0.000	3.706
	EB-AR	0.006	0.475	0.858	0.970	0.034	0.000	2.344
	PG-P	0.004	0.155	0.219	0.225	0.230	0.000	0.831
	PG-A	0.004	0.065	0.171	0.204	0.221	0.000	0.665
	PG-R	0.006	0.310	0.273	0.062	0.000	0.000	0.650
	SP-P	0.007	0.009	0.065	0.133	0.212	0.387	0.812
	SP-R	0.000	0.026	0.152	0.366	0.186	0.000	0.730

(continued)

Table 1 (concluded).

Misc.	CB-P	0.000	0.004	0.104	0.042	0.000	0.000	0.149
Taxa	CB-A	0.000	0.006	0.007	0.012	0.000	0.000	0.024
	CB-R	0.001	0.003	0.014	0.167	0.167	12.969	13.320
	EB-P	0.015	0.020	0.051	0.004	0.000	0.000	0.090
	EB-A	0.034	0.029	0.021	0.013	0.031	0.000	0.128
	EB-PR	0.066	0.077	0.050	0.000	0.000	1.529	1.722
	EB-AR	0.004	0.015	0.030	0.037	0.027	0.000	0.113
	PG-P	0.000	0.007	0.188	0.118	0.299	0.000	0.612
	PG-A	0.000	0.019	0.003	0.473	0.277	0.000	0.772
	PG-R	0.001	0.040	0.082	0.193	0.809	0.977	2.102
	SP-P	0.000	0.042	0.023	0.157	0.215	2.631	3.073
	SP-R	0.000	0.008	0.024	0.000	0.000	0.000	0.032

Table 2. Distribution of fish food habits samples among four Puget Sound disposal areas. Fish size classes listed as Standard Length (SL). CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage. n = number of individual stomachs containing identifiable prey.

DISPOSAL AREA	CB SL(cm)	n	EB SL(cm)	n	PG SL(cm)	n	SP SL(cm)	n
SPECIES								
Dover Sole	25-30	3	20-25	9	15-20	3		
	30-35	9	25-30	7	20-25	13		
			30-35	10	25-30	13		
					30-35	3		
Slender Sole			5-10	5	15-20	4	10-15	7
			10-15	23			15-20	12
			15-20	46				
English Sole	20-25	8			20-25	28		
					25-30	17		
Flathead Sole			10-15	5				
			15-20	13				
Rex Sole	10-15	3	5-10	3				

TOTALS

DISPOSAL AREA	CB	EB	PG	SP
	23	121	81	19

SPECIES	Slender Sole	Dover Sole	English Sole	Flathead Sole	Rex Sole
	97	70	53	18	6

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Table 3. Description of prey size feeding strategy groups.

Group I   - Fishes feeding on prey less than or equal to 1.0 mm or smaller
             with a modal prey size around 0.25 mm. No representatives of
             this group were found in this data set.

Group II - Fishes that exploit a range of prey sizes and that are not
             clearly small prey or large prey exploiters. Group II contains
             four subgroups in this data set.

        Group IIA - Fishes that exploit prey between 0.25 and 2.0 mm.
                     A prey size mode of 0.5 mm is indicated for
                     benthic prey items.

        Group IIB - Fishes that exploit prey between 0.5 and 3.35 mm.
                     A prey size mode of 2.0 mm is indicated.

        Group IIC - Fishes that exploit prey between 0.5 and 3.35 mm.
                     A prey size mode of 3.35 mm is indicated.

        Group IID - Fishes that exploit prey in the 3.35 mm size
                     category.

Group III - Fishes that do not exploit small sized prey. Exploitation is
             predominantly among prey that are greater than 3.35 mm.   Two
             subgroups occur in this data set.

        Group IIIA - Fishes that exploit prey in the intermediate size
                     range (0.5-2.0 mm), but the prey size mode is 6.35
                     mm.

        Group IIIB - Fishes that exploit only prey in the 6.35 mm size
                     category.

Table 4. Composition of feeding strategy groups based on prey size exploitation patterns.

GROUP	SPECIES	SIZE CLASS (cm, SL)	NUMBER OF INDIVIDUALS	SITE
II	Flathead Sole	10-15	5	Elliott Bay (1-T5)
IIA	Rex Sole	5-10	3	Elliott Bay (1-T6,8)
	Slender Sole	5-10	5	Elliott Bay (1-T6,8)
	Slender Sole	10-15	10	Elliott Bay (1-T6,8)
	Slender Sole	15-20	19	Elliott Bay (2)
	Dover Sole	15-20	3	Port Gardner (1)
	Dover Sole	20-25	5	Port Gardner (1)
	Dover Sole	20-25	4	Elliott Bay (2)
IIB	Slender Sole	10-15	7	Saratoga Passage
	Slender Sole	15-20	12	Saratoga Passage
	Slender Sole	15-20	4	Porp Gardner (2)
	Dover Sole	25-30	3	Port Gardner (R2)
	Dover Sole	25-30	3	Port Gardner (R1)
	Dover Sole	25-30	7	Elliott Bay (2)
	Dover Sole	30-35	3	Commencement Bay (2)
	Dover Sole	30-35	6	Commencement Bay (RD)
	English Sole	20-25	8	Commencement Bay (RS)
	English Sole	20-25	8	Port Gardner (1)
	English Sole	25-30	3	Port Gardner (2)
IIC	Slender Sole	15-20	6	Elliott Bay (R1)
	Dover Sole	20-25	5	Elliott Bay (1-T6,8)
	Dover Sole	20-25	8	Port Gardner (2)
	Dover Sole	25-30	7	Port Gardner (2)
	Dover Sole	30-35	3	Port Gardner (2)
	English Sole	20-25	20	Port Gardner (2)
IID	Rex Sole	10-15	3	Commencement Bay (RS)
IIIA	Flathead Sole	15-20	6	Elliott Bay (R1)
	Slender Sole	10-15	7	Elliott Bay (1-T7)
	Slender Sole	10-15	3	Elliott Bay (2)
	Slender Sole	15-20	10	Elliott Bay (1-T5)
	Slender Sole	15-20	11	Elliott Bay (1-T6,8)
	Dover Sole	25-30	3	Commencement Bay (2)
	Dover Sole	30-35	10	Elliott Bay (2)
	English Sole	25-30	14	Port Gardner (2)
IIIB	Flathead Sole	15-20	3	Elliott Bay (1-T5)
	Flathead Sole	15-20	4	Elliott Bay (1-T6,8)
	Slender Sole	10-15	3	Elliott Bay (1-T5)

Table 5. Feeding efficiency of fishes sampled at four disposal areas in Puget Sound, as indicated by mean weight of food items (including benthos and nekton) per stomach. CB = Commencement Bay, EB = Elliott Bay, PG = Port Gardner, SP = Saratoga Passage.

SPECIES	Size Class (cm, SL)	Mean Weight of Food Per Stomach (g)			
		CB	EB	PG	SP
Slender Sole	5-10	.094 (5)			
	10-15		0.102 (23)		0.112 (7)
	15-20		0.209 (46)	0.280 (4)	0.120 (12)
Dover Sole	15-20			0.209 (3)	
	20-25		0.661 (9)	0.442 (13)	
	25-30	0.413 (3)	0.523 (7)	0.653 (13)	
	30-35	0.788 (9)	2.859 (10)	0.824 (3)	
English Sole	20-25	0.771 (8)		0.731 (28)	
	25-30			1.505 (17)	
Flathead Sole	10-15		0.094 (5)		
	15-20		0.512 (13)		
Rex Sole	5-10	0.835 (3)			
	10-15		0.067 (3)		

Table 6. Mean biomass (g/sq m) of non-excluded taxa within different sediment depth fractions for benthic strata in the Puget Sound study areas.

| | | Size (mm) | | | | | |
		0.25	0.50	1.00	2.00	3.35	6.35
Depth Fraction:0-2 cm							
Stratum A		0.032	0.311	0.484	0.776	0.701	0.409
	AA	0.000	0.490	3.410	0.537	0.840	0.000
	B	0.061	0.799	4.560	2.479	1.381	0.000
	C	0.048	1.362	5.115	1.922	4.881	0.000
	CC	0.125	2.283	5.284	3.915	3.452	3.054
	D	0.590	1.152	9.032	5.764	1.880	0.098
Depth Fraction:0-5 cm							
Stratum A		0.032	0.407	0.794	1.358	1.839	1.341
	B	0.093	1.146	6.033	6.301	3.434	0.000
	BB	0.139	1.415	7.356	3.028	3.444	2.341
	C	0.032	1.839	8.385	5.271	7.835	0.525
	CC	0.000	1.391	4.486	3.845	7.792	4.375
	D	0.417	2.051	7.426	5.297	13.934	7.103
Depth Fraction:0-10 cm							
Stratum A		0.038	0.499	0.811	1.316	2.796	4.413
	B	0.093	1.569	7.017	6.649	4.300	0.000
	BB	0.071	1.379	6.231	3.849	5.552	3.852
	C	0.216	2.037	7.236	6.335	15.644	13.607
	CC	0.000	2.936	11.943	11.762	6.700	1.698
	D	0.083	1.734	8.391	8.014	10.067	62.393
Depth Fraction:0-15 cm							
Stratum A		0.029	0.250	0.772	1.294	1.383	3.437
	AA	0.038	1.302	1.570	3.346	9.438	6.438
	AAA	0.000	1.495	8.413	3.561	4.025	5.654
	B	0.135	2.151	6.327	5.488	14.447	11.365
	BB	0.000	2.905	11.241	11.517	6.168	1.273
	BBB	0.046	1.265	6.809	7.115	4.740	18.332
	C	0.000	2.008	8.174	7.054	19.429	16.695
	D	0.113	1.599	7.167	8.015	12.859	62.354

Table 7. Benthic resource analysis for Group IIA predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A				
0.25	+	0-5	0.032	0.032
0.50	+	"	0.407	0.407
1.00	+	"	0.794	0.794
2.00	+	"	1.358	1.358
3.35	-	"	1.839	0.000
6.35	-	"	1.341	0.000
				2.591
Stratum B				
0.25	+	0-5	0.093	0.093
0.50	+	"	1.146	1.146
1.00	+	"	6.033	6.033
2.00	+	"	6.301	6.301
3.35	-	"	3.434	0.000
6.35	-	"	0.000	0.000
				13.573
Stratum BB				
0.25	+	0-5	0.139	0.139
0.50	+	"	1.415	1.415
1.00	+	"	7.356	7.356
2.00	+	"	3.028	3.028
3.35	-	"	3.444	0.000
6.35	-	"	2.341	0.000
				11.938
Stratum C				
0.25	+	0-5	0.032	0.032
0.50	+	"	1.839	1.839
1.00	+	"	8.385	8.385
2.00	+	"	5.271	5.271
3.35	-	"	7.835	0.000
6.35	-	"	0.525	0.000
				15.527
Stratum CC				
0.25	+	0-5	0.000	0.000
0.50	+	"	1.391	1.391
1.00	+	"	4.486	4.486
2.00	+	"	3.845	3.845
3.35	-	"	7.835	0.000
6.35	-	"	4.375	0.000
				9.712
Stratum D				
0.25	+	0-5	0.417	0.417
0.50	+	"	2.051	2.051
1.00	+	"	7.426	7.426
2.00	+	"	5.297	5.297
3.35	-	"	13.974	0.000
6.35	-	"	7.103	0.000
				15.191

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Table 8. Benthic resource analysis for Group IIB predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A				
0.25	-	0-10	0.038	0.000
0.50	+	"	0.499	0.499
1.00	+	"	0.811	0.811
2.00	+	"	1.316	1.316
3.35	+	"	2.796	2.796
6.35	-	"	4.413	0.000
				5.422
Stratum B				
0.25	-	0-10	0.093	0.000
0.50	+	"	1.569	1.569
1.00	+	"	7.017	7.017
2.00	+	"	6.649	6.649
3.35	+	"	4.300	4.300
6.35	-	"	0.000	0.000
				19.535
Stratum BB				
0.25	-	0-10	0.071	0.000
0.50	+	"	1.379	1.379
1.00	+	"	6.231	6.231
2.00	+	"	3.849	3.849
3.35	+	"	5.552	5.552
6.35	-	"	3.852	0.000
				17.011
Stratum C				
0.25	-	0-10	0.216	0.000
0.50	+	"	2.037	2.037
1.00	+	"	7.236	7.236
2.00	+	"	6.335	6.335
3.35	+	"	15.644	15.644
6.35	-	"	13.607	0.000
				31.252
Stratum CC				
0.25	-	0-10	0.000	0.000
0.50	+	"	2.936	2.936
1.00	+	"	11.943	11.943
2.00	+	"	11.762	11.762
3.35	+	"	6.700	6.700
6.35	-	"	1.698	0.000
				33.341
Stratum D				
0.25	-	0-10	0.083	0.000
0.50	+	"	1.734	1.734
1.00	+	"	8.391	8.391
2.00	+	"	8.014	8.014
3.35	+	"	10.067	10.067
6.35	-	"	62.393	0.000
				28.206

Table 9. Benthic resources analysis for Group IIC predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A				
0.25	-	0-5	0.032	0.000
0.50	+	"	0.407	0.407
1.00	+	"	0.794	0.794
2.00	+	"	1.358	1.358
3.35	+	"	1.839	1.839
6.35	-	"	1.341	0.000
				4.398
Stratum B				
0.25	-	0-5	0.093	0.000
0.50	+	"	1.146	1.146
1.00	+	"	6.033	6.033
2.00	+	"	6.301	6.301
3.35	+	"	3.434	3.434
6.35	-	"	0.000	0.000
				16.914
Stratum BB				
0.25	-	0-5	0.139	0.000
0.50	+	"	1.415	1.415
1.00	+	"	7.356	7.356
2.00	+	"	3.028	3.028
3.35	+	"	3.444	3.444
6.35	-	"	2.341	0.000
				15.243
Stratum C				
0.25	-	0-5	0.032	0.000
0.50	+	"	1.839	1.839
1.00	+	"	8.385	8.385
2.00	+	"	5.271	5.271
3.35	+	"	7.835	7.835
6.35	-	"	0.525	0.000
				23.330
Stratum CC				
0.25	-	0-5	0.000	0.000
0.50	+	"	1.391	1.391
1.00	+	"	4.486	4.486
2.00	+	"	3.845	3.845
3.35	+	"	7.792	7.792
6.35	-	"	4.375	0.000
				17.514
Stratum D				
0.25	-	0-5	0.417	0.000
0.50	+	"	2.051	2.051
1.00	+	"	7.426	7.426
2.00	+	"	5.297	5.297
3.35	+	"	13.974	13.974
6.35	-	"	7.103	0.000
				28.748

Table 10. Benthic resource analysis for Group IIIA predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A				
0.25	-	0-10	0.038	0.000
0.50	-	"	0.499	0.000
1.00	-	"	0.811	0.000
2.00	-	"	1.316	0.000
3.35	+	"	2.796	2.796
6.35	+	"	4.413	4.413
				7.209
Stratum B				
0.25	-	0-10	0.093	0.000
0.50	-	"	1.569	0.000
1.00	-	"	7.017	0.000
2.00	-	"	6.649	0.000
3.35	+	"	4.300	4.300
6.35	+	"	0.000	0.000
				4.300
Stratum BB				
0.25	-	0-10	0.071	0.000
0.50	-	"	1.379	0.000
1.00	-	"	6.231	0.000
2.00	-	"	3.849	0.000
3.35	+	"	5.552	5.552
6.35	+	"	3.852	3.852
				9.404
Stratum C				
0.25	-	0-10	0.216	0.000
0.50	-	"	2.037	0.000
1.00	-	"	7.236	0.000
2.00	-	"	6.335	0.000
3.35	+	"	15.644	15.644
6.35	+	"	13.607	13.607
				29.251
Stratum CC				
0.25	-	0-10	0.000	0.000
0.50	-	"	2.936	0.000
1.00	-	"	11.943	0.000
2.00	-	"	11.762	0.000
3.35	+	"	6.700	6.700
6.35	+	"	1.698	1.698
				8.398
Stratum D				
0.25	-	0-10	0.083	0.000
0.50	-	"	1.734	0.000
1.00	-	"	8.391	0.000
2.00	-	"	8.014	0.000
3.35	+	"	10.067	10.067
6.35	+	"	62.393	62.393
				72.460

APPENDICES

SEATTLE DISTRICT - BRAT EVALUATION

LOCATION	DATE	TIME	DEPTH (m)	BOTTOM TYPE	BOX CORER WT(lbs)	PENETRATION DEPTH(cm)	COORDINATES
CB-AD-1	16 June 1986	0930	178	silty-clay	120	30	Radar: 1.71 Ascaro Corner / 1.05 Brown's Pt — TD: 27896.4 / 42248.9
CB-AD-2	16 June 1986	1027	178	silty-clay	120	23	Radar: 1.43 Ascaro Corner / 1.28 Brown's Pt — TD: 27893.1 / 42249.5
CB-AD-3	16 June 1986	????	175	silty-clay	160	40	Radar: 1.46 Ascaro Corner / 1.00 Brown's Pt / 1.76 Neill's Pt — TD: 27892.4 / 42250.7
CB-AD-4	16 June 1986	1215	175	silty-clay	160	28	Radar: 1.73 Ascaro Corner / 0.78 Brown's Pt / 1.76 Neill's Pt — TD: 27894.0 / 42252.7
CB-RA-1	16 June 1986	1242	174	silty-clay	160	35	Radar: 2.20 Ascaro Corner / 0.87 Brown's Pt / 1.08 Dash Pt — TD: 27891.1 / 42252.1
CB-RA-2	16 June 1986	1404	174	silty-clay	160	40	Radar: 0.54 Brown's Pt / 2.00 Neill's Pt / 0.98 Dash Pt — TD: 27888.4 / 42251.6
CB-RA-3	16 June 1986	1432	173	silty-clay	160	35	Radar: 0.41 Brown's Pt / 2.23 Neill's Pt / 1.35 Dash Pt — TD: 27888.1 / 42251.5
CB-RA-4*	16 June 1986	1452	172	silty-clay	160	22	Radar: 0.45 Brown's Pt / 1.40 Dash Pt — TD: 27892.0 / 42249.0
CB-PD-5	16 June 1986	1518	173	silty-clay	160	35	Radar: 1.34 Ascaro Corner / 1.01 Brown's Pt / 1.84 Neill's Pt — TD: 2789.8 / 42247.7
CB-PD-6	16 June 1986	1538	171	silty-clay	160	40	Radar: 1.05 Ascaro Corner / 1.28 Brown's Pt / 1.93 Neill's Pt / 2.12 Dash Pt

Station	Date	Time		Substrate			Radar	TD
CB-PD-7	16 June 1986	1624	169	silty-clay	160	40	Radar: 1.47 Ascaro Corner / 0.86 Brown's Pt / 2.23 Neill's Pt	TD: 27888.6 / 42249.3
CB-PD-8	16 June 1986	1700	171	silty-clay	160	40	Radar: 1.09 Ascaro Corner / 1.23 Brown's Pt / 2.05 Neill's Pt	TD: ------ / ------
EB-AD-1	17 June 1986	0850	167	sandy-silt	160	35	Radar: 0.83 shore / 1.46 SW 91	TD: 28021.9 / 42249.3
EB-AD-2	17 June 1986	0929	158	sandy-silt	160	18	Radar: 1.29 SW 91 / 0.71 shore	TD: 28021.1 / 42291.4
EB-AR-1*	17 June 1986	1002	176	silty-clay	160	40	Radar: 1.70 SW 91 / 1.08 shore	TD: 28022.1 / 42289.0
EB-AR-2	17 June 1986	1041	183	silty-clay	160	50	Radar: 1.47 SW 91 / 1.23 shore	TD: 286.5 / 42290.3
EB-AD-3	17 June 1986	1057	173	silty-clay	169	28	Radar: 1.42 SW 91 / 0.98 shore	TD: 28019.8 / 42290.5
EB-AD-4	17 June 1986	????	170	silty-clay	160	38	Radar: 1.11 SW 91 / 0.86 shore	TD: 28017.0 / 42291.7
EB-AD-5	17 June 1986	1145	181	silty-clay	120	38	Radar: 1.20 SW 91 / 1.09 Mag. Bluff Shore	TD: 28014.8 / 42291.5
EB-PR-6	17 June 1986	1249	88	silty-clay	80	40	Radar: 1.65 SW 91 / 1.25 NW 46 / 0.64 Duwamish Head Shore	TD: 27998.6 / 42295.9
EB-PD-7	17 June 1986	1343	79	silty-clay	120	40	Radar: 1.89 SW 91 / 0.84 NW 46 / 1.00 Duwamish Head Shore	TD: 27996.0 / 42298.0
EB-PD-3	17 June 1986	1325	82	silty-clay	80	40	Radar: 1.61 SW 91 / 1.00 NW 46	TD: 27998.6 / 42297.8
EB-PD-8*	17 June 1986	1410	64	silty-clay	80	40	Radar: 1.84 SW 91 / 1.0 NW 46	TD: 27996.3 / 42297.0

Station	Date	Time		Sediment			Radar	TD
EB-PR-9	17 June 1986	1435	87	silty-clay	80	40	Radar: 1.88 SW 91 / 1.30 NW 46 / 0.50 Duwamish Head Shore	TD: 27997.3 / 42295.7
EB-PD-4	17 June 1986	1455	61	silty-clay	80	35	Radar: 2.10 SW 91 / 0.71 Duwamish Head Shore	TD: 27994.5 / 42296.7
EB-PD-10	17 June 1986	1523	76	silty-clay	80	40	Radar: 2.00 SW 91 / 0.92 Duwamish Head Shore	TD: 27995.0 / 42297.8
PG-RA-1	18 June 1986	1149	135	silty-clay	80	38	Radar: 1.50 RBN / 2.50 SW corner of S. Pier / 1.52 Edgewater (nearest shore)	TD: 28172.3 / 42356.4
PG-PD-2	18 June 1986	1210	130	silty-clay	80	30	Radar: 1.41 RBN / 1.57 Edgewater / 2.29 SW crner of S. Pier	TD: 28172.1 / 42357.7
PG-PD-3	18 June 1986	1231	133	silty-clay	80	25	Radar: 1.51 RBN / 1.65 Edgewater / 1.89 SW corner of S. Pier	TD: 28170.7 / 42354.9
PG-PD-4	18 June 1986	1256	126	silty-clay	80	35	Radar: 1.52 RBN / 1.50 Edgewater / 2.07 SW corner of S. Pier	TD: 28170.5 / 42358.5
PG-PD-5	18 June 1986	1312	130	silty-clay	80	35	Radar: 1.73 RBN / 1.27 Edgewater / 2.14 SW corner of S. Pier	TD: 28169.0 / 42357.5
PG-PD-6	18 June 1986	1331	128	silty-clay	80	38	Radar: 1.81 RBN / 1.30 Edgewater / 1.75 SW corner of S. Pier	TD: 28167.5 / 42359.5
PG-RA-7	18 June 1986	1403	134	silty-clay	80	40	Radar: 2.09 RBN / 0.90 Edgewater / 2.00 SW corner of S. Pier	TD: 28165.3 / 42357.5
PG-AD-8	18 June 1986	1420	126	silty-clay	80	30	Radar: 2.17 RBN / 0.93 Darlington / 1.59 SW corner of S. Pier	TD: ------- / -------

Station	Date	Time			Sediment		Radar	TD
PG-AD-9	18 June 1986	1440	109	80	silty-clay	35	Radar: 2.43 RBN / 0.89 Darlington / 1.13 SW corner of S. Pier	TD: ------ / ------
PG-AD-10*	18 June 1986	1513	120	120	silty-clay	22	Radar: 0.60 Darlington / 1.29 SW corner of S. Pier	TD: ------ / ------
SP-PD-1	19 June 1986	0912	105	80	fine silt	32	Radar: 1.00 Saratoga Point / 1.62 N edge of Mabama / 2.20 S edge of Lowell Pt	TD: 28269.1 / 42339.0
SP-PD-2	19 June 1986	0937	108	80	silty-clay	40	Radar: 1.17 Saratoga Pt / 1.42 N edge of Mabama / 2.30 S edge of Lowell Pt	TD: 28268.3 / 42341.0
SP-PD-3	19 June 1986	0959	105	80	silty-clay	40	Radar: 0.99 Saratoga Pt / 1.43 N edge of Mabama / 2.50 S edge of Lowell Pt	TD: 28265.9 / 42340.4
SP-RA-4	19 June 1986	1025	104	80	silty-clay	40	Radar: 0.62 Saratoga Pt / 1.82 N edge of Mabama	TD: 28266.0 / 42338.4

KEY TO LOCATIONS: CB = Commencement Bay   PG = Port Gardner   EB = Elliott Bay   SP = Saratoga Passage

PD = Primary Disposal Site   RA = Reference Area
AD = Alternative Disposal Site   PR = Primary Reference
                                 AR = Alternative Reference

* NOTES

CB-R-4: 10% of 10-15 cm fraction lost.
EB-2-1: fairly coarse sediment with an obvious dredged material overburden.
EB-1-8: sediment here much more cohesive than preceding samples.
PG-10:   sandy sediment below thin, fine surface layer.

END

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